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HURRICANES OF 1951

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GENERAL SUMMARY

Ten tropical disturbances, eight of them full hurricanes, were charted in the Atlantic during the 1951 season. This is slightly above the normal number, but generally speaking, the season was an average one, and presented no more than the usual tracking and forecasting problems.

No winds of hurricane force occurred on the coast of the United States, and only one disturbance, less than hurricane force, struck the mainland during the season. This storm crossed southern Florida from the Gulf of Mexico on October 2, and gave flooding rains and winds up to 60 m. p. h. in squalls. Damage has been estimated at about $2,000,000 but there was no loss of life. This is the smallest damage figure for tropical storms in the United States since 1939, but other places were not so fortunate. The Island of Jamaica suffered its worst hurricane disaster of the century on August 17–18 when hurricane "Charlie" caused about $50,000,000 in property and crop damage, killed 152 persons, injured 2,000 others, and left 25,000 homeless. The same storm did extensive crop damage when it crossed northern Yucatan the night of the 19th. On August 22 it entered Mexico near Tampico where upward of 100 people lost their lives, principally from bursting dams and flooding rivers. Property and crop losses were in the millions of dollars.

The first hurricane of the season developed east of the Florida coast during the night of May 16. This is the earliest date known for a fully developed hurricane in the Atlantic. There are records of several tropical storms in May during past years, but none developed hurricane force. Moore and Davis [1] have discussed the physical and dynamic forces involved in this hurricane and other interesting features surrounding its development.

The next storm was noted on August 2 and thereafter storm activity was brisk until October 20 when the last hurricane of the season dissipated over the Atlantic southwest of Bermuda.

The Miami Hurricane Central coordinated and dispatched more than 100 reconnaissance aircraft flights into hurricanes during the season, and coordinated and issued a total of 156 advisory bulletins. These indicate the active nature of the season, but the totals are well below the record established in 1950. Total damage in the Caribbean area will probably exceed $80,000,000 and there were more than 250 fatalities.

This was another season with several instances of two or more storms in progress simultaneously. Referring to the track chart (fig. 1), it will be noted that hurricanes "Dog" and "Easy" were in progress on September 3–5, while a third hurricane "Fox," appeared on September 5 and was a companion of "Easy" until the 10th. Again on October 15–16, hurricanes "Item" and "Jig" were in progress at the same time. This is the second consecutive year with multiple hurricanes, a rather rare occurrence in the Atlantic. An interesting feature of hurricanes "Easy" and "Fox" was their slight counterclockwise movement which took place when the two approached each other in the Atlantic near Bermuda. This apparently caused the great hurricane "Easy" to veer enough to miss Burmuda, which had been threatened with destructive winds before the counterclockwise tendency became apparent on September 8.

INDIVIDUAL HURRICANES

Able.—May 16–24.—The earliest fully developed hurricane of record in the Atlantic developed east of Florida during the night of May 16. At 0700 EST on the 17th, the steamship *R. P. Smith* reported winds of Beaufort force 9 to 10, falling pressure, and waves 25 to 30 feet high near 28.5° N., 79.5° W. This was the first definite

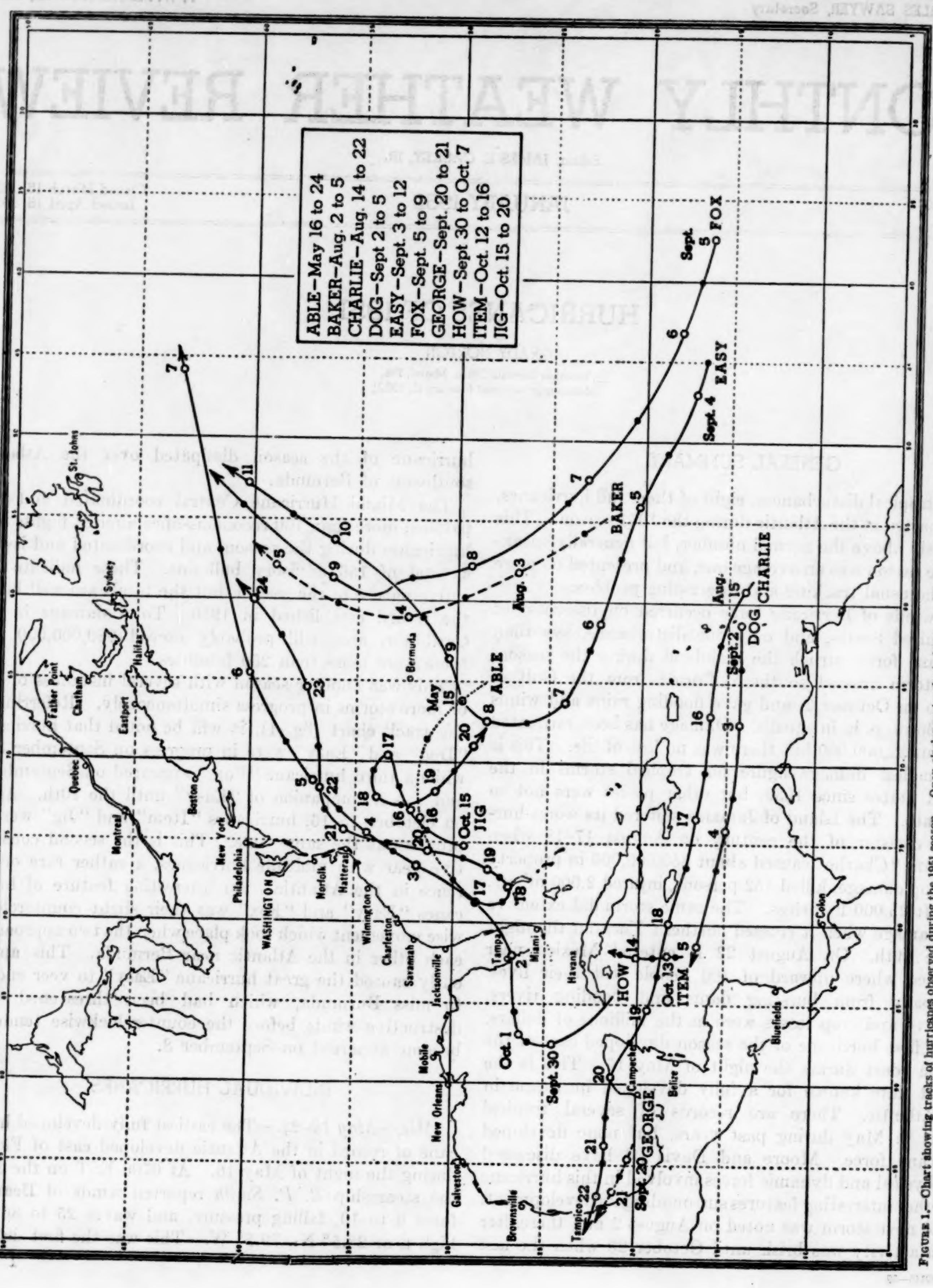

FIGURE 1. Chart showing tracks of hurricanes observed during the 1951 season. Open circles on tracks indicate position of center at 1 a. m., EST., solid circles, position at 7 p. m. Solid tracks indicate full hurricane winds, dashed lines less than full hurricane winds. Dotted tracks represent probable course during incipient stage.

information that a severe storm had formed. The Navy reconnaissance squadron had just arrived at Miami for servicing prior to the beginning of the season and was ordered out immediately to get full reports. During the 17th they reported a storm of full hurricane strength moving southward. It was later determined that the hurricane was moving on a broad curving loop which brought it over the Little Bahama Banks during the night of the 17th and on the 18th. Walker's Cay on these banks reported 90 to 95 m. p. h. winds for 5 hours during the night of the 17–18th, and Grand Bahama and Little Abaco islands both reported about the lower limits of hurricane force. The completion of the loop turned the hurricane northeastward over the Atlantic and it passed 70 miles east of Cape Hatteras on the 21st. Thereafter it turned toward the east-northeast and dissipated over the Atlantic near 40° N., 60° W. on May 24. The strongest winds were estimated by aircraft at 100 knots (115 m. p. h.) on the 21st. The central "eye" was well formed and about 20 miles in diameter during much of the storm's life and the central pressure was well below 29 inches. (Moore and Davis [1] have investigated this hurricane more fully.)

Baker.—August 2–5.—An "easterly wave" developed into a tropical storm far to the northeast of the Leeward Islands on August 2, near 23° N., 56° W. It moved on a broad curving path to the northwest and north and passed about 275 miles east of Bermuda on August 4 and thereafter turned northeastward over the Atlantic. This storm did not develop hurricane force; the strongest winds reported were only 60 m. p. h.

Charlie.—August 14–22.—A partially developed "easterly wave" appeared east of the Lesser Antilles on August 14 and moved northwestward through the islands early on the 15th, without causing damage. Aircraft reported squalls of 90 knots east of Martinique on the afternoon of the 14th, but the island weather stations did not report winds stronger than 35 m. p. h. There is some evidence that a small center of strong winds passed between Dominica and Guadeloupe during the morning of the 15th. At any rate, there was regeneration to full hurricane force again during the next 24 hours. The center skirted the south coast of Jamaica during the night of the 17th and the entire island had destructive winds, which caused the worst hurricane disaster of the century on Jamaica. Property and crop damage was estimated at $50,000,000, 152 persons were killed, and 2,000 others injured, and about 25,000 made homeless. The strongest wind at Kingston was estimated at over 110 m. p. h.; lowest pressure, 28.74 inches (973 mb.); and rainfall, 17 inches. The center passed several miles south of the city.

After the hurricane left Jamaica, Grand Cayman experienced 92 m. p. h. winds in gusts, but the next land area seriously affected was the Yucatan Peninsula, which the hurricane crossed during the night of the 19th. Reports indicate heavy crop losses running to 70 percent, but no loss of life in the Yucatan area. The storm entered the Gulf near Merida and Progreso on the morning of the 20th considerably reduced in force, but it regained its former force before entering Mexico near Tampico on August 22. Tampico was near the southern edge of the "eye" and reported winds of 110 m. p. h. but winds were doubtless stronger to the north of the calm center. Property damage was estimated at $1,160,000 in the city of Tampico and 4 persons were killed; torrential rains flooded rivers and burst dams in the country west and northwest of the city and caused more than 100 deaths by drowning, according to final press reports.

The exact number of casualties could not be ascertained since many bodies were evidently not recovered in the flood area. Property damage was in the millions of dollars, but actual estimates are not available. The strongest winds reported in this hurricane were about 130 m. p. h. (by aircraft) just before it entered Yucatan, and again in the Gulf off Tampico. The pressure at Tampico dropped to 28.81 inches (975.7 mb.). The total loss of life in this hurricane was almost certainly over 250, while property and crop damage will probably reach a total of $75,000,000.

Dog.—September 1–5.—Reconnaissance planes located a disturbance several hundred miles east of Barbados on September 1, and on the morning of the 2d it was found to be a partially developed wave, with squalls of hurricane force in its northeastern quadrant, a short distance east of Martinique. Winds on the southern side were weak. On September 2, it moved through the Lesser Antilles between Santa Lucia and Martinique. Both islands suffered considerable damage. On Martinique 1,000 homes were reported destroyed and many others unroofed; 5 persons lost their lives by drowning; trees which were uprooted blocked roads and tore down telephone and power lines; 90 percent of the banana crop, and 30 percent of the sugarcane crop were lost; damage was about $3,000,000. On Santa Lucia, two persons lost their lives by drowning, and one sailing vessel was destroyed and two others damaged; flooding and high winds destroyed 70 percent of the banana crop in the northern part of the island. The strongest wind reported in the islands was 100 knots (115 m. p. h.) at Fort-De-France Airport on September 2. Total damage was well over $3,000,000 and seven people were killed.

After the hurricane entered the Caribbean Sea, it began losing force and by the time its westward course brought it to a position some 200 miles southeast of Swan Island on the 5th, it had dissipated into moderate squalls and thereafter disappeared entirely.

Easy.—September 3–12.—The steamship *Barn* sent three special reports on the morning of September 3 which indicated the existence of a circulation, probably of hurricane force, near 16.5° N., 42.5° W. It was followed thereafter by aircraft which reported it to be of hurricane force and increasing as it moved on a west-northwestward

course. By the time it began curving northward on the 7th near 25° N., 67° W., aircraft reported it to be too severe for penetration. The wind reached an estimated 140 knots at deepest penetration on the south side when the plane had to turn back. This indicated that a possible wind of between 160 and 200 m. p. h. was prevailing near the center and on the stronger northern side. This was by far the most severe hurricane of the 1951 season. It curved sharply and passed a short distance southeast of Bermuda on the 9th and continued northeastward and was well off Newfoundland by the 12th. This great hurricane did not strike any land area, but a few ships were involved more or less and suffered damage to their superstructures. There was no loss of life. Lowest pressure reported as 28.26 in. (957.0 mb.) on the 6th.

Fox.—September 5–9.—This hurricane was first suspected when the steamship *Janecke Naess* encountered 45-knot south winds at 15° N., 35° W. on September 5. This wind report indicated that a small hurricane center was located a short distance northwest of the ship's position. It later proved to be a small, fast-moving hurricane which moved on a northwestward course and passed some 350 miles east of Bermuda on September 8. Thereafter it turned northeastward and continued its rapid movement over the Atlantic. It passed well to the east of Newfoundland on the 10th. It will be noted that this hurricane's entire life was co-existent with the great hurricane "Easy." When the two were nearest Bermuda on the 8th, they exerted the usual counterclockwise torque on each other, which probably prevented "Easy" from striking the island. The strongest winds reported by aircraft for "Fox" were 115 to 120 m. p. h. A few ships were involved to some extent but no damage reports have been received.

George.—September 20–21.—A tropical storm of less than hurricane force developed in the Gulf of Campeche on September 20 and moved into Mexico a short distance south of Tampico on the 21st. The strongest wind reported was about 60 m. p. h. (by aircraft) during the afternoon on the 20th. No damage has been reported in connection with this storm.

How.—October 1–7.—An easterly wave moved into the Gulf of Mexico through the Yucatan Channel the last 2 days of September, and on October 1 reconnaissance planes located a center of circulation near 26.0° N., 87.5° W. attended by squally winds of about 40 m. p. h. This center turned sharply eastward and crossed Florida from about Punta Gorda to Vero Beach on October 2. The strong winds associated with the disturbance while passing over Florida were confined to squalls along the Keys and on the east coast up to Palm Beach far to the southeast of the center; they reached 50 to 60 m. p. h. The center was not strongly organized at this time and was not attended by damaging wind, but it was attended by a belt of torrential rains along its path, which caused extensive flooding of farm and pasture lands, including much of the rich farm land around Lake Okeechobee. A considerable number of cattle were drowned and some that could not be moved from flooded ranges to high ground died of starvation. Wind damage was confined to canvas awnings, a few glass windows, and sinking or damage to some small craft along the Keys and lower east coast. In all, damage was estimated at about $2,000,000; no loss of life or injuries occurred.

After leaving Florida the storm increased to hurricane force as it moved northeastward in the Atlantic. It passed a short distance offshore from Cape Hatteras on October 4, without damaging winds on land, and continued northeastward and then east-northeastward and passed several hundred miles south of Nova Scotia and Newfoundland on the 6th and 7th. The strongest winds reported were about 110 m. p. h.

Item.—October 12–16.—A very small hurricane developed in the northwestern Caribbean Sea on October 12 near 18° N., 82° W. It moved slowly northward to a position 60 to 80 miles east-southeast of the Isle of Pines where it became stationary, or made a small loop, and slowly dissipated on the 15th and 16th. Strongest winds reported by aircraft were around 80 m. p. h. maintained from the 13th to 15th. No damage resulted from this hurricane. Lowest central pressure reported was 29.45 in. (997.3 mb.).

Jig.—October 15–20.—The last hurricane of the season developed off the south Atlantic coast on October 15 near 30° N., 75° W. A semicircular area of hurricane force winds of around 75 to 80 m. p. h. developed north of the center and persisted for a couple of days as it moved slowly northeastward. On the 17th and 18th, the center described a loop westward and then southward between Bermuda and Cape Hatteras and lost force. It finally died out several hundred miles southwest of Bermuda on October 20. Several ships were involved in the storm, but no reports of damage have been received.

REFERENCE

1. Paul L. Moore and Walter R. Davis, "A Preseason Hurricane of Subtropical Origin," *Monthly Weather Review*, vol. 79, No. 10, October 1951, pp. 189–195.

CORRESPONDENCE

REMARKS ON "PERSISTENCE OF EXTREMELY WET AND EXTREMELY DRY MONTHS IN THE UNITED STATES"

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January 7, 1952

I was very interested to see the paper "Persistence of extremely wet and extremely dry months in the United States," by Messrs. C. S. Gilman and J. T. Riedel (*Monthly Weather Review*, vol. 79, No. 3, March 1951, pp. 45–49). The extension to the United States network of rainfall stations of such investigations into the problem of persistency of dry and wet spells will, I am sure, be welcomed by workers in statistical climatology.

However, there are certain points in this account which are not strictly correct and I should like to divert the authors' attention to them. The paper referred to as [5] (Beer, Drummond, and Fürth, *Quarterly Journal of the Royal Meteorological Society*, vol. 72, No. 311, January 1946, pp. 74–86) is, I feel, misrepresented. The following amendments are relevant:

(a) The rainfall data discussed in that paper are not the same British data as used by Cochran (reference [4]), but were specially assembled for the former investigation. The length of record available at the seven selected stations varied between 70 and 130 years. This material represented five distinctly different rainfall regimes (annual rainfall 610–3,440 mm.) and certainly the most homogeneous long-period rainfall records existing for the British Isles. It was considered that the treatment had to be confined to such measurements if reliable results were to be expected.

(b) Table 2 in Gilman and Riedel's paper purports to refer to the British Isles generally, but this is not so. The values quoted, establishing the absence of correlation between the amounts of rainfall in successive months, are those for only one of the stations, viz. Kew Observatory (1856–1944). This is however of minor importance as broadly similar results apply to the other six stations.

(c) The statement which appears in the last paragraph of section 2 (p. 46, col. 2) of Gilman and Riedel's paper, "Summarizing: In England there seems to be a tendency towards persistence for wet and dry months, the tendency being slightly stronger for dry," is at variance with the conclusions arrived at in the Beer, Drummond, and Fürth paper. Now, the latter work clearly established that a close relationship existed between m, the number of successive like months, and F, the frequency with which such a series occurred; namely $\log F = Rm + S$, where R and S are constants for each station. After a statistical examination for the absence of correlation (standard χ^2 test for independence), a mathematical theory was advanced on the basis that the sequences were purely accidental. The probability formulae obtained explained fully the empirical relationship, giving a satisfactory representation of the observational data. This result is evident in the following extract from table II of the original paper.

Frequencies per 100 years of specified runs of wet and dry months at certain stations in the British Isles

General averages (5 stations: annual rainfall 770–3,440 mm.)

Runs of at least (months)	Wet months		Dry months	
	Observed	Calculated	Observed	Calculated
1	301	292	303	292
2	131	134	157	158
3	60	61	87	86
4	27	28	43	46
5	12	12	24	25
6	5.8	5.9	13	14
7	1.3	2.7	6.0	7.4
8	.8	1.2	2.9	4.0
9	.5	.6	1.9	2.2
10	.2	.3	1.0	1.2
11	.2	.1	.4	.6
12	0	0	.2	.3

At the same time it was pointed out that the degree of divergence between the corresponding wet and dry lines (i. e. plots of $\log F$ against m) exhibited in some way the meteorological character of the particular station. Since the size of this angle depends upon the ratio p/q (where p and q = the proportion of dry and wet months respectively in the total), it expresses the amount of asymmetry of the rainfall frequency curve. This significant relationship appears to be a rather complex one, as was brought out by trial plots of the ratios against various rainfall constants.

Finally, it was emphasized that the independence of consecutive rainfall figures is obviously due to the length of the period examined (i. e. 1 month in this instance) and that a statistical "after effect" will come into play for sufficiently short periods. In this latter case the statistical distribution would be different from that observed above and a similar "stirring up" of the order of events would alter the frequencies instead of leaving them unchanged. The investigation of such shorter periods should lead to results of considerable practical

importance to meteorologists in so far as determining the length of period within which consecutive events of "wetness" and "dryness" affect each other.

REPLY

C. S. GILMAN AND J. T. RIEDEL
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January 25, 1952

Mr. Drummond is quite right in pointing out that the data analyzed by Beer, Drummond, and Fürth are not the same as those analyzed by Cochran and that the data in our table 2 refer specifically to Kew rather than generally to the British Isles. With regard to the conclusions regarding persistence in England, we feel that although the χ^2-value in our table 2 (Beer, Drummond and Fürth data) is not significant, the results of earlier investigators do show significance. Specifically Cochran's data, as shown in our table 1, give a significant value of χ^2. In view of the known insensitivity of the χ^2-test to type II error we feel that more weight should be given to the results of tests that do show significance. Presumably the chance explanation given in part 3 of the paper by Beer, Drummond, and Fürth would not have been applied to data with significant χ^2-values.

THE WEATHER AND CIRCULATION OF JANUARY 1952[1]

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The first month of 1952 was characterized by relatively mild winter weather in about three-fourths of the United States. This is portrayed in Chart I-B where it may be seen that in almost all portions of the country eastward from the Plateau region temperatures averaged above January normals. Temperature departures exceeded +6° F. in a broad belt extending from Colorado and New Mexico eastward to the Atlantic Coast as well as in the Ohio Valley and Middle Atlantic States. The warmest weather, with respect to normal, was found in eastern Texas and southwestern Louisiana. As an example of the warmth in Texas, Fort Worth reported maximum temperatures in excess of 70° F. on almost half the days of the month. The only areas in the Nation with below-normal temperatures were the Far West and the northern border States west of Wisconsin, where wintry weather was often quite severe.

As might be expected from the predominant warmth over the United States, the upper air flow pattern in the Nation consisted of waves with relatively small amplitude, so that zonal flow predominated over meridional

[1] See Charts I-XV following page 13 for analyzed climatological data for the month.

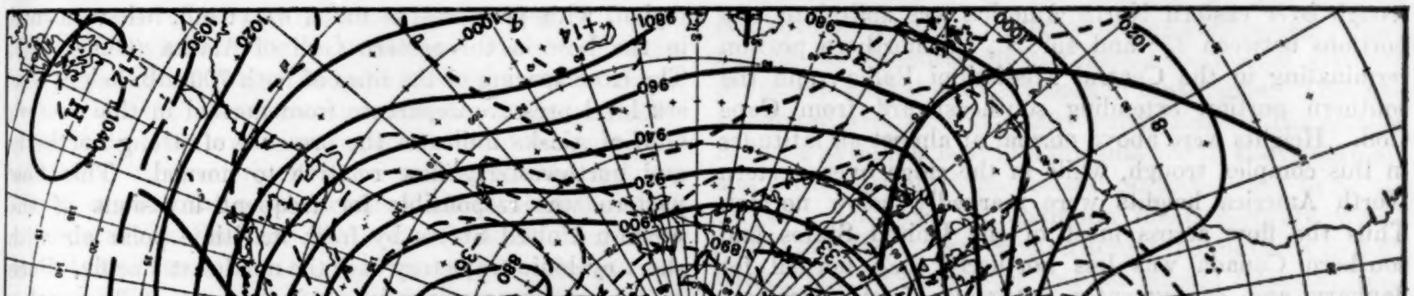

FIGURE 1.—Mean 700-mb. chart for the 30-day period January 1-30, 1952. Contours at 200-ft. intervals are shown by solid lines, intermediate contours by lines with long dashes, and 700-mb. height departures from normal at 100-ft. intervals by lines with short dashes with the zero isopleths heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines.

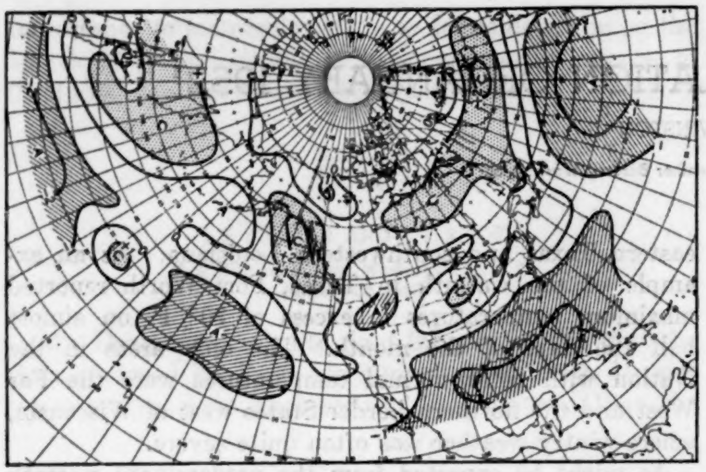

FIGURE 2.—Vertical component of mean relative geostrophic vorticity at 700 mb. for the 30-day period January 1–30, 1952 in units of 10^{-5} sec^{-1}. Areas of cyclonic vorticity in excess of 1×10^{-5} sec^{-1} are stippled and labeled "C" at the center; areas of anticylonic vorticity less than -1×10^{-5} sec^{-1} are hatched and labeled "A" at the center.

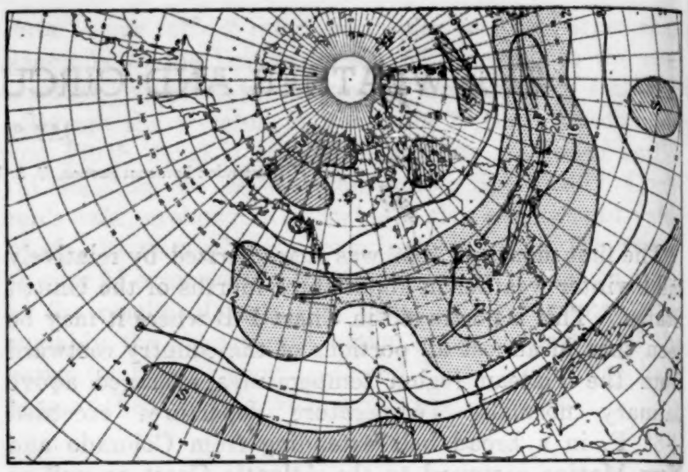

FIGURE 3.—Mean geostrophic (total horizontal) wind speed at 700 mb. for the 30-day period January 1–30, 1952. Solid lines are isotachs at intervals of 4 m/sec while the double arrowed lines delineate the axes of maximum wind speeds (jets). Areas with speeds in excess of 12 m/sec are stippled while those with less than 4 m/sec are hatched. Centers of maximum and minimum wind speed are labeled "F" and "S" respectively.

motion (Charts XII–XV). At 700 mb. (fig. 1) the trough over eastern North America was split into two portions between 35° and 45° N., the northern portion terminating in the Central Mississippi Valley, and the southern portion extending southeastward from Cape Cod. Heights were above normal at almost all latitudes in this complex trough, while in the ridge over western North America heights were markedly below normal. Thus the flow across most of the United States and southern Canada was less northerly than normal for January, and, consequently, outbreaks of cold polar continental air into the United States were less frequent and less severe than usual. In fact, Chart IX shows that most of the anticyclone centers which originated in or traversed the northwest Canadian source region moved almost directly eastward across southern Canada. Of those which did cross into the United States only the one which was in North Carolina on the 31st penetrated south of 35° N. It is evident from Chart IX that there were many other daily anticyclones traversing the United States during this month, but most of these centers originated east of the Continental Divide as offshoots from the semi-permanent "Basin High" and were composed predominantly of mild modified Pacific maritime polar air.

It is also interesting to point out the direct relationship between the pattern of 700-mb. height departure from normal (fig. 1) and the surface temperature anomaly (Chart I–B). Note especially that the maximum positive height departure from normal over the United States is located in east Texas, where the greatest positive surface temperature anomaly occurred.

Other important features of the circulation pattern aloft were the abnormally deep trough off the west coast of North America and the abnormally strong ridge to its west, extending from western Alaska to a High center northeast of Hawaii. The anomaly patterns of sea level pressure and 700-mb. height were fairly similar in this region, with pressures as much as 11 mb. below normal in the Low in the eastern Gulf of Alaska (Chart XI). The close spacing of the lines of both 700-mb. height and sea level pressure departure from normal in the western Gulf of Alaska indicates the presence of strong northerly and northwesterly flow relative to normal. This flow pattern was responsible for frequent invasions of the western United States by fresh maritime polar air with short cyclonic trajectory over the northeast Pacific. Such air masses are notorious for producing wet, chilly weather along the West Coast (Charts I–B and III).

Cyclonic activity in the Gulf of Alaska and along the West Coast (Chart X) was extremely frequent and intense. The intensity of mean cyclonic vorticity in the deep 700-mb. trough in this region is clearly portrayed in figure 2. As many as 11 individual daily storm centers traversed an area of the northeastern Gulf of Alaska between 55° and 60° N. and 135° and 145° W. during the month. Close inspection of the tracks in Chart X reveals that in the first two-thirds of the month the bulk of the storms moved eastward and southeastward near the coastal boundary of the Gulf of Alaska. Near midmonth a few storms dropped as far south as coastal California at the time when the eastern Pacific trough reached its greatest intensity at lower latitudes. These cyclones, and several fronts moving eastward during the second decade of the month, produced some extremely heavy precipitation in California and other parts of the Southwest (Chart III). Intense rainfall at lower elevations resulted in flooding of many streams in Arizona and central and southern California, and deep snowfall at higher elevations in the Sierras blocked highways and railroad lines.[2] Additional significant precipitation fell in California on the 24th and 25th as a storm approached the

[2] Details about the most damaging storm of this series can be found in the following article by Carr.

coast from the west-southwest and crossed northern California. This general orientation of storm tracks from southwest to northeast in the eastern Pacific in the last decade of the month was associated with weakening of the mean trough along the West Coast and development of southwesterly flow aloft in the eastern Pacific.

Cyclones traversed most sections of North America east of the Continental Divide during January (Chart X), as indicated by the predominance of cyclonic vorticity over most of Canada and the northern half of the United States east of the Divide (fig. 2). The prevailing storm path in the United States ran roughly from the Central Plains northeastward across the Great Lakes and closely followed the axis of maximum wind speed at 700 mb. (fig. 3). The tracks of the more intense storms were mostly located just north of this axis, generally following the channel of cyclonic vorticity shown in figure 2. To the north of these storms, in the Northern Plains and the Lakes region, precipitation, largely in the form of snow, was in excess of normal (Charts III and V–A). To the south of the paths of the major storms, over the southern half of the Plains States and also along the eastern slopes of the Rockies, precipitation amounts were generally subnormal. This is not surprising in view of the relatively flat prevailing westerly flow across the Divide and the lack of continental polar air masses banked against the east side of the Rockies. Thus Pacific air blowing over the Divide descended the eastern slopes almost unhampered by stagnant cold continental air masses, so that dry warm weather typical of pronounced foehn activity was the rule. At Caspar and Cheyenne, Wyo., and Rapid City, S. Dak., no measurable precipitation fell during the entire month (Chart II).

Precipitation was also deficient in the Southeast, where anticyclonic conditions and above-normal heights prevailed at 700 mb. (figs. 1 and 2). In other sections east of the Mississippi, northward from Tennessee and North Carolina, precipitation amounts generally exceeded the seasonal normals. This is attributable to the mean trough at 700 mb. extending northeastward from the central Mississippi Valley (fig. 1) and the stronger-than-normal flow from the Gulf of Mexico at sea level (Chart XI). The most excessive precipitation in this region occurred in the Ohio Valley where heavy rains fell during the last week of the month. Thunderstorms were reported at this time and some stations in Ohio recorded rainfall amounts totaling as much as 3 inches in 24 hours.

Several cyclones developed near the east coast of the United States and contributed to much of the heavy precipitation along the Atlantic Seaboard. Most of these deepened in the region of cyclonic vorticity (fig. 2) off the northeast section of the coast. About half of these storms traveled northward into the broad area of stronger cyclonic vorticity in northeastern Canada and the Greenland-Iceland area. The remaining half of these cyclones were steered east-northeastward across the Atlantic, generally parallel to the monthly mean contours (fig. 1), and rather close to the pronounced monthly mean 700-mb. jet stream across the northern sections of the Atlantic (fig. 3).

The westerlies in the northeastern Atlantic between latitudes 50° and 60° N. were considerably stronger than normal, as evidenced by the strong meridional gradient of 700-mb. height anomaly lines in that region. This was associated with an abnormally strong ridge in the eastern Atlantic at middle latitudes (heights 520 ft. above normal) and a deep trough from Iceland northeastward to Spitzbergen. The axis of maximum mean monthly winds at 700 mb. (fig. 3) was located across the southern British Isles. The persistence of this jet stream from the previous month [1] resulted in continuing storminess in the vicinity of the British Isles especially in the first fortnight of the month. It was during this period that the freighter *Flying Enterprise*, which had been crippled by storminess late in December, finally sank as all efforts to save her failed in the tempestuous seas off Falmouth, England.

REFERENCE

1. W. H. Klein, "The Weather and Circulation of December 1951," *Monthly Weather Review*, vol. 79, No. 12, December 1951, pp. 218–221.

A WINTER STORM AT LOS ANGELES, CALIFORNIA

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INTRODUCTION

The first 3 weeks of January 1952 were notable because of the large amount of storminess over the eastern Pacific Ocean. During these weeks, nearly every Low in the northern Pacific moved east along the southern coast of Alaska and then southeastward off the west coast of Canada (Chart X).

On January 12, one such storm was noted near Kodiak, Alaska. In the following 5 days it moved southward toward the coast of California, where, on the morning of the 17th, it seemed about to dissipate. However, on this date, one of the minor vortices associated with this area of cyclonic circulation apparently deepened and began moving toward California. Early on the morning of the 18th, it moved inland between Los Angeles and San Diego.

This storm brought damage and disaster to the region of Los Angeles, while depositing 7.37 in. (Jan. 15–18) of rain on the city proper. The rainfall on the 15th to 16th (3.39 in.) was related to the passage of a cold front which moved down the coastline as a low pressure moved into northern Nevada. The fall of 3.98 in. on the 17th to 18th was directly related to the storm which moved inland near Los Angeles.

Considerable property damage resulted from earth slides and some flooding in the Los Angeles River District.

PRECIPITATION FACTORS

The Hydrometeorological Section of the U. S. Weather Bureau [1, 2] found certain definite factors were involved in the production of rainfall over southern California. One report [1] states, "Cyclonic systems which result in gradient winds from the southwest quadrant over southern California produce precipitation, and the intensity of precipitation varies directly with the wind velocity and dewpoint but inversely with the distance of the cyclonic system from the area." This report emphasizes the importance of an orographic barrier by reporting it as the main controlling feature for the production and distribution of rainfall, and concludes that in major general storms orographic lifting of stable air is sufficient to account for the precipitation intensities in the Los Angeles area. For maximum storm amounts the optimum gradient wind direction at Los Angeles should be from 210° [2]. In summation, moisture supply, its rate of inflow from a critical direction and orography are keys to the production of rainfall over California.

THE CIRCULATION PATTERN

The southwesterly air flow aloft during the rain period, at Los Angeles, is illustrated by figure 1. Incidentally, the Low off northern California moved northeastward over southeastern Oregon during the following 24 hours in connection with the Low entering the Gulf of Alaska. This related movement, of the two Lows, is in agreement with the findings of Henry [3].

The trough over the Gulf of Alaska, like the others before it, filled as it moved along the north end of the ocean ridge, but later, deepened as it traveled southeastward in the main trough off the west coast of North America (see the preceding article by Winston). The moving trough over the Gulf was the upper air counterpart of the surface storm which moved to a point west of San Francisco by the 17th.

Figures 2 and 3 indicate the day to day changes in the deep flow of southwesterly winds which supplied consider-

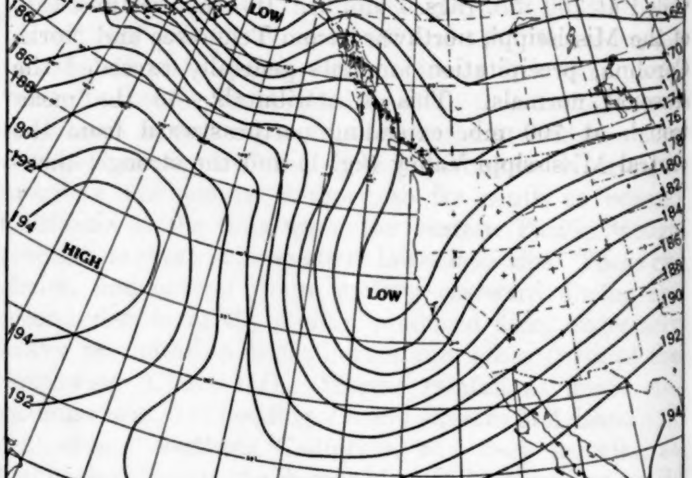

Figure 1.—500 mb. chart, 1500 GMT, January 12, 1952. Contour lines at intervals of 200 geopotential feet.

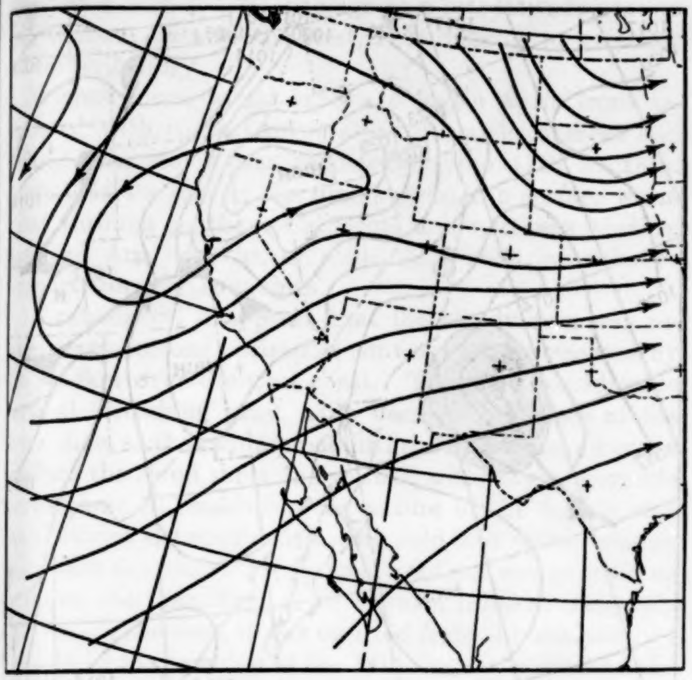

Figure 2.—Airflow chart, 1500 GMT, January 17, 1952. Solid lines represent the airflow parallel to the contour lines at the 500-mb. surface.

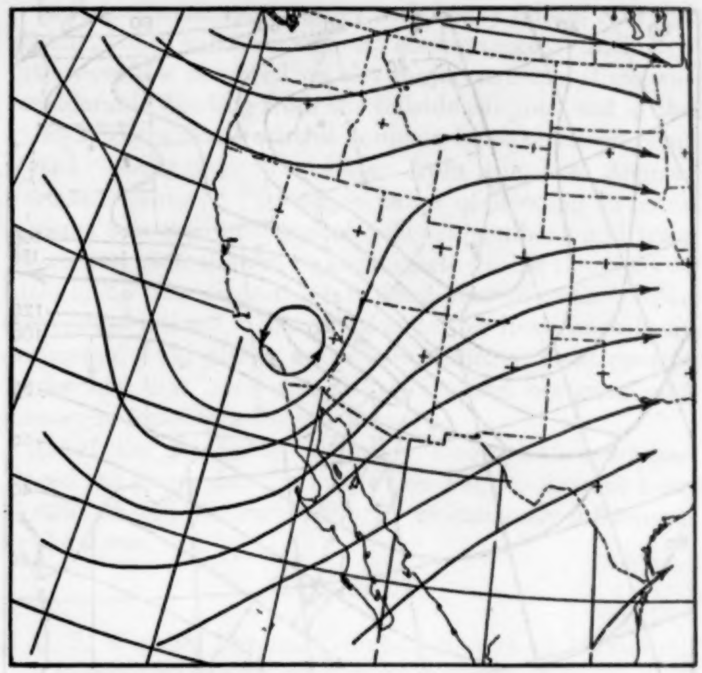

Figure 3.—Airflow chart, 1500 GMT, January 18, 1952.

able moisture, from a favorable direction, to southern California. From an inspection of the first 3 figures an important observation is suggested by the flow patterns, that considerable horizontal convergence was taking place at the southern end of the upper trough. Plotted winds on the original charts support this observation. That this activity was discernible to very high levels can be inferred from a comparison of the *jet stream* position in figure 4 with the flow patterns of figures 2 and 3.

On the morning of the 18th (fig. 3) it was evident that the upper cold Low was filling as, concurrently, a westerly to northwesterly wind had begun to invade the length of the Pacific Coast. As a consequence, the moisture supply was cut off and the rainfall at Los Angeles ceased approximately 2 hours after the time represented by figure 3.

It is of passing interest to note the position and strength of the *jet streams* (figs. 4 and 5) before the rain stopped at Los Angeles. In this storm, it appears that a relationship might exist between the location of the upper *jet* and surface areas of precipitation. As pointed out by Starrett [4], for cases of *jet streams* associated with troughs, the maximum of precipitation occurs to be north of the *jet* and east of the trough.

THE DEEPENING IMPULSE

Intimately connected with the upper trough over the Gulf of Alaska was the down-wind pressure surge with its characteristic of super-geostrophic winds moving southward. Presumably, a similar surge supplied the impulse for the apparent development (or regeneration) of the surface vortex on the 17th. Necessarily implied is a strong cross-isobar flow, which also represents considerable horizontal divergence. Such divergence works to produce pressure falls and, normally, could be expected to accentuate a tendency toward falling pressure in a surface Low beneath it. Of course the relationship is not so simple and straightforward, but at least its contribution is in that direction. In this case it appears that the moving area of divergence effectively removed mass from the region above the small surface vortex and the result was deepening. The movement of the surface Low after the 17th was guided by the movement of the upper trough.

SURFACE ANALYSIS

With the paucity of reports from the ocean area it is difficult to determine whether the storm, indicated in figure 6, was active before or became more active after the first hint of its existence at 33° N. and 127° W. at 0630 GMT on the 17th.

However, the analysis for 0030 GMT (18th) showed the circulation apparently had deepened some 5 mb. and was moving toward Los Angeles and San Diego where the sea level pressure had dropped about 5 mb. during the preceding 6 hours. The possible cause of this development was described in a previous paragraph.

Coincident with the drop in coastal pressures, rain began to fall along the coast from San Diego north, to just beyond Burbank and Los Angeles. In the following hours rain overspread all of southern California and Arizona.

From the standpoint of analysis and forecasting this storm presented some difficulties. The cold front depicted in the surface illustrations was not drawn on the original

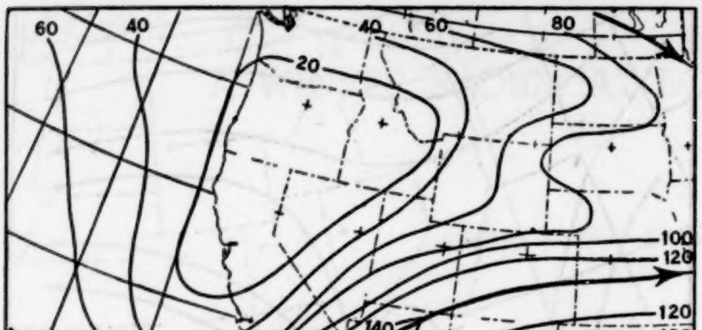

Figure 4.—200-mb. isotach chart, 0300 GMT, January 18, 1952. Solid lines are drawn at intervals of 20 knots, heavy solid line indicates the *jet stream* axis.

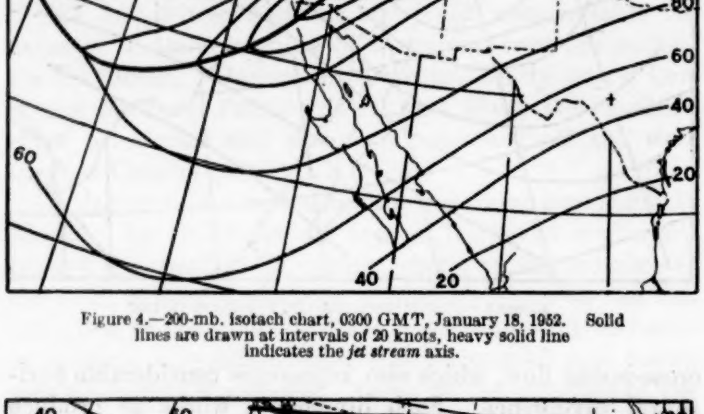

Figure 5.—200-mb. isotach chart, 1500 GMT, January 18, 1952.

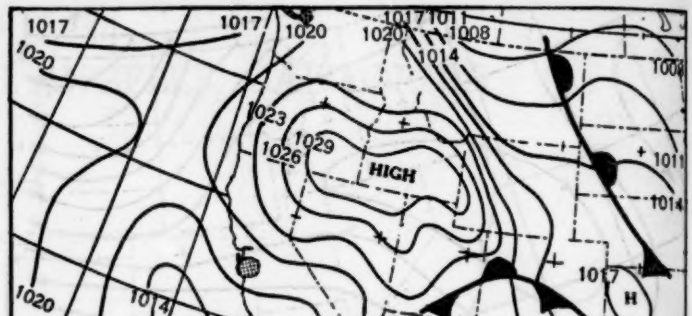

Figure 6.—Surface chart, 1830 GMT, January 17, 1952. Shaded area indicates precipitation in progress.

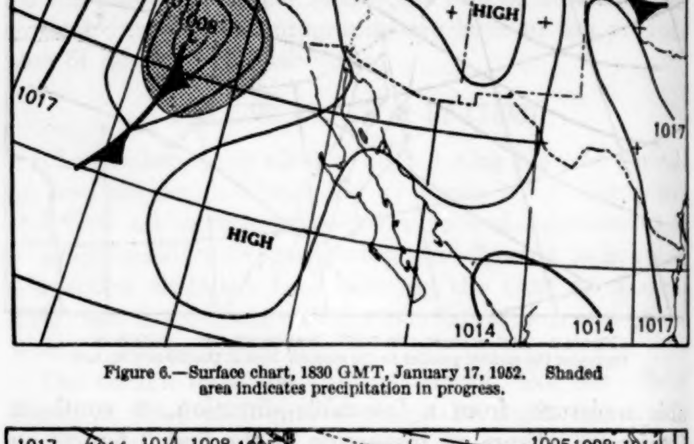

Figure 7.—Surface chart, 1830 GMT, January 18, 1952.

analysis. Only after determining the position of the cold front over Arizona (on the 18th) and redrawing the preceding maps was it possible to include the cold front in figure 6.

Actually this cold front was identifiable out over the ocean upon the basis of incomplete reports from Guadaloupe, Mexico. Prior to its arrival, Guadaloupe reported (0300 GMT on the 18th) a SSE wind, rain and a 3-hr. pressure change of −3.2 mb. Judging by ship reports, in the vicinity, the cold front passed the island after 0630 GMT (18th) and by 1230 GMT winds were WSW as far east as San Diego. The next report from Guadaloupe, (at 1830 GMT) on the 18th, showed a brisk NW wind, Partly Cloudy, and a 3-hr. pressure rise of 3.9 mb. So,

this was a cold frontal passage at a low latitude station but without data to the west, it is difficult to ascertain its earlier history.

Normally, one would expect to find a warm front associated with the extensive alto-stratus cloud sheet and steady rain which was reported on the 17th to 18th. Some field stations at the time suggested a surface warm front through southern California and northern Mexico, but the Analysis Center could find only inconclusive support from the soundings.

In retrospect, it appears that the steady rain was related to the strong horizontal convergence represented by the air flow over the west coast. Therefore considerable vertical stretching must have been taking place at the same time, so that widespread lifting of the moist air could produce the cloud sheet and rainfall without a discernible warm front. Considering the nature of the terrain and the distance between contrasting cold and warm sources it appears the horizontal thermal gradient was so weak as to make the identification of a warm front an uncertain process. Therefore, it was omitted from the analysis.

Early in the morning of the 18th the storm reached the coast where it split into 2 centers as the rainfall came to an end over the southern end of the State. By midmorning (local time) the storm had moved to Arizona (fig. 7).

STORM DAMAGE

Following the storm period the total amount of rainfall at Los Angeles during the balance of the month was 0.65 in. The total for the month was 10.03 in. which is the third highest total for January in the history of the station. It was also the highest January total since the record 13.30 in., set in 1916. Such a monthly total represents a considerable percentage of the annual rainfall which, in the mean, is slightly over 15 in.

In the mountainous country such heavy falls of rain are, usually, not without serious consequences. Although little overflow occurred on the major streams, there was considerable flooding from the hillside canyons and in the valleys where flood control projects have not been completed. According to a letter from the Los Angeles Forecast Center, "The major cause of flooding in some streams was the collection of debris, shrubbery and trees which had been allowed to accumulate during the years of little or no flow since the last flood year of 1943." The same letter stated, "Many communities have been built on natural flood plains, and where sufficient flood control works had not been completed flooding occurred and numerous families were evacuated."

As of the middle of February incomplete estimates placed the storm damage in the Los Angeles Area at near $5,000,000 with 21 deaths directly or indirectly influenced by the storm.

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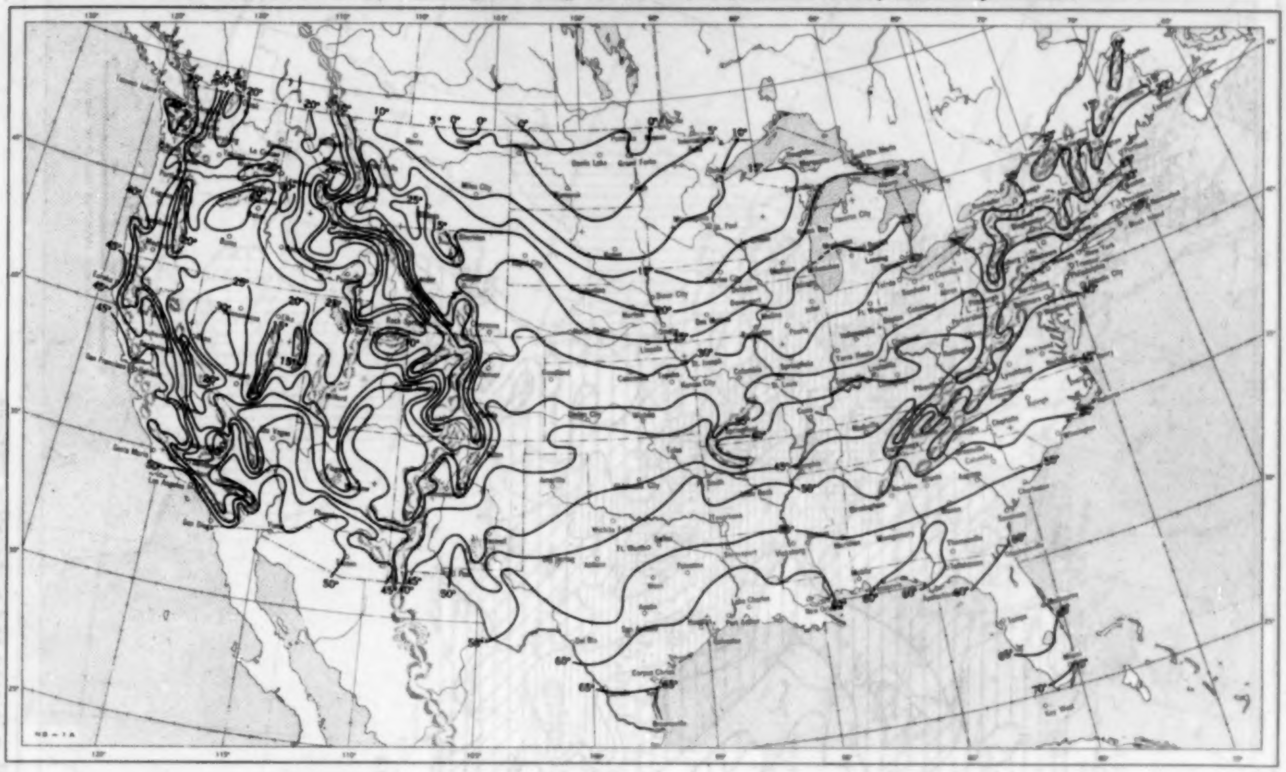
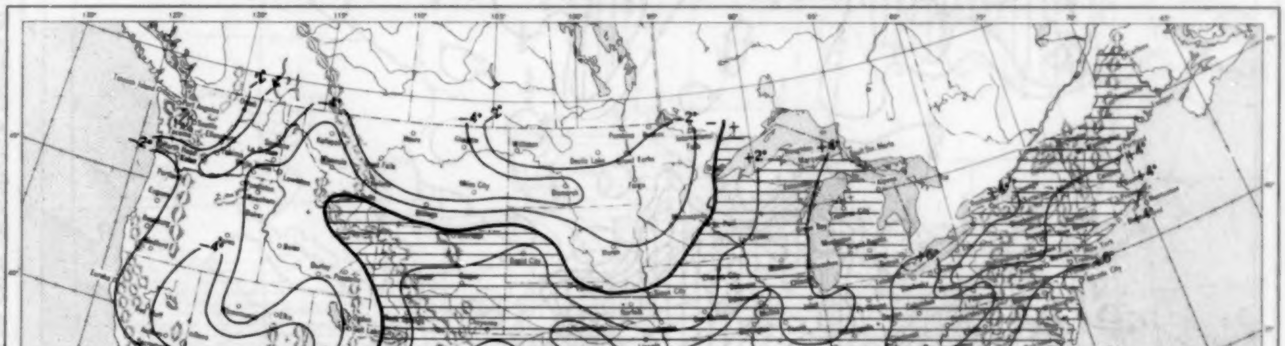
1. U. S. Weather Bureau, "Revised Report on Maximum Possible Precipitation, Los Angeles Area, California," *Hydrometeorological Report No. 21B*, Washington, D. C., December 1945.
2. U. S. Weather Bureau, "Maximum Possible Precipitation, San Joaquin Basin, California," *Hydrometeorological Report No. 24*, Washington, D. C., July 1947.
3. Walter K. Henry, "On the Movement of the Southwest Low," a thesis submitted in candidacy for the degree of Master of Science, University of Chicago, September 1949 (unpublished).
4. L. G. Starrett, "The Relation of Precipitation Patterns in North America to Certain Types of Jet Streams at the 300 millibar level," *Journal of Meteorology*, vol. 6, No. 5, October 1949, pp. 347–352.

U. S. GOVERNMENT PRINTING OFFICE: 1951

Chart I. A. Average Temperature (°F.) at Surface, January 1952.

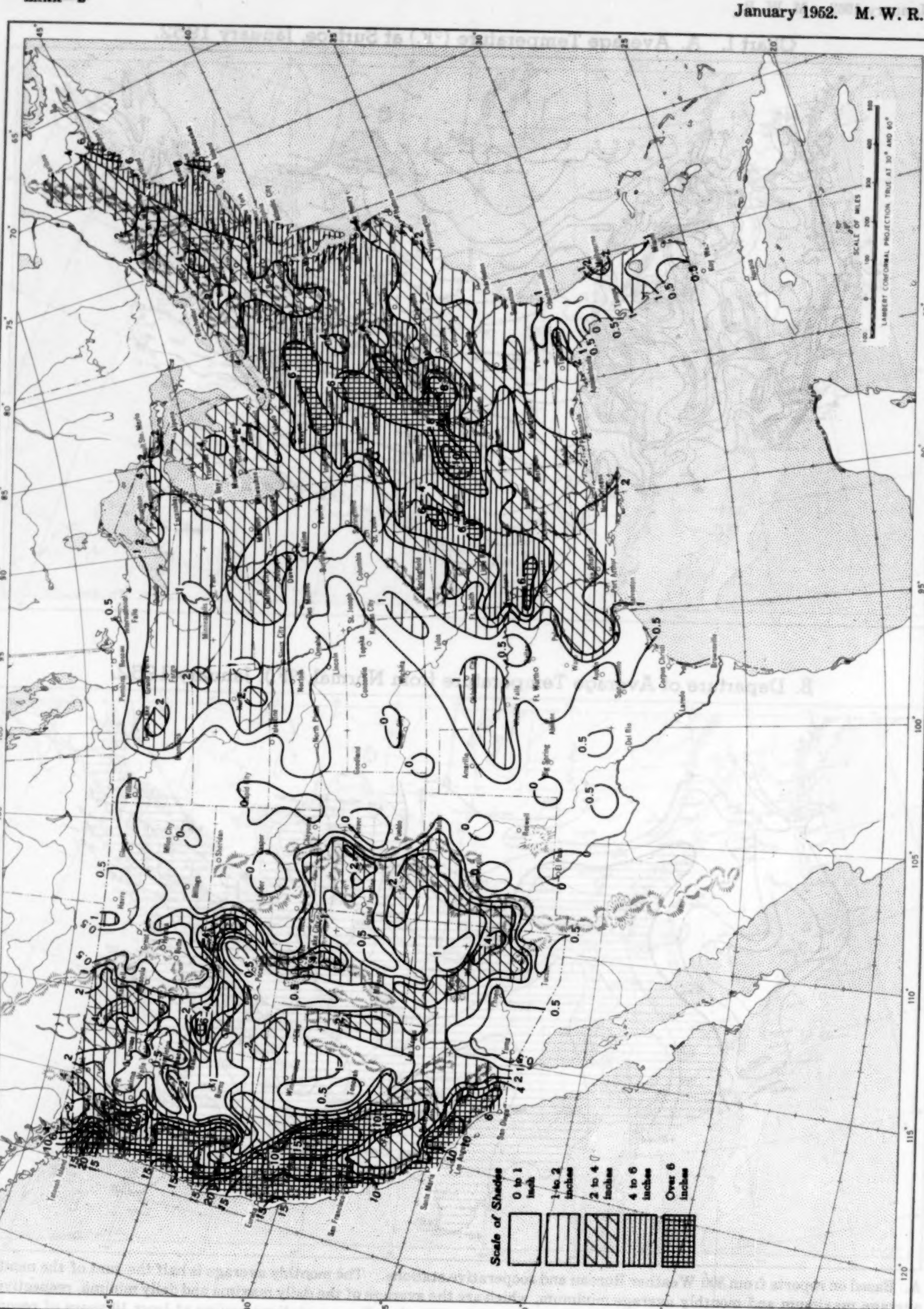


B. Departure of Average Temperature from Normal (°F.), January 1952.



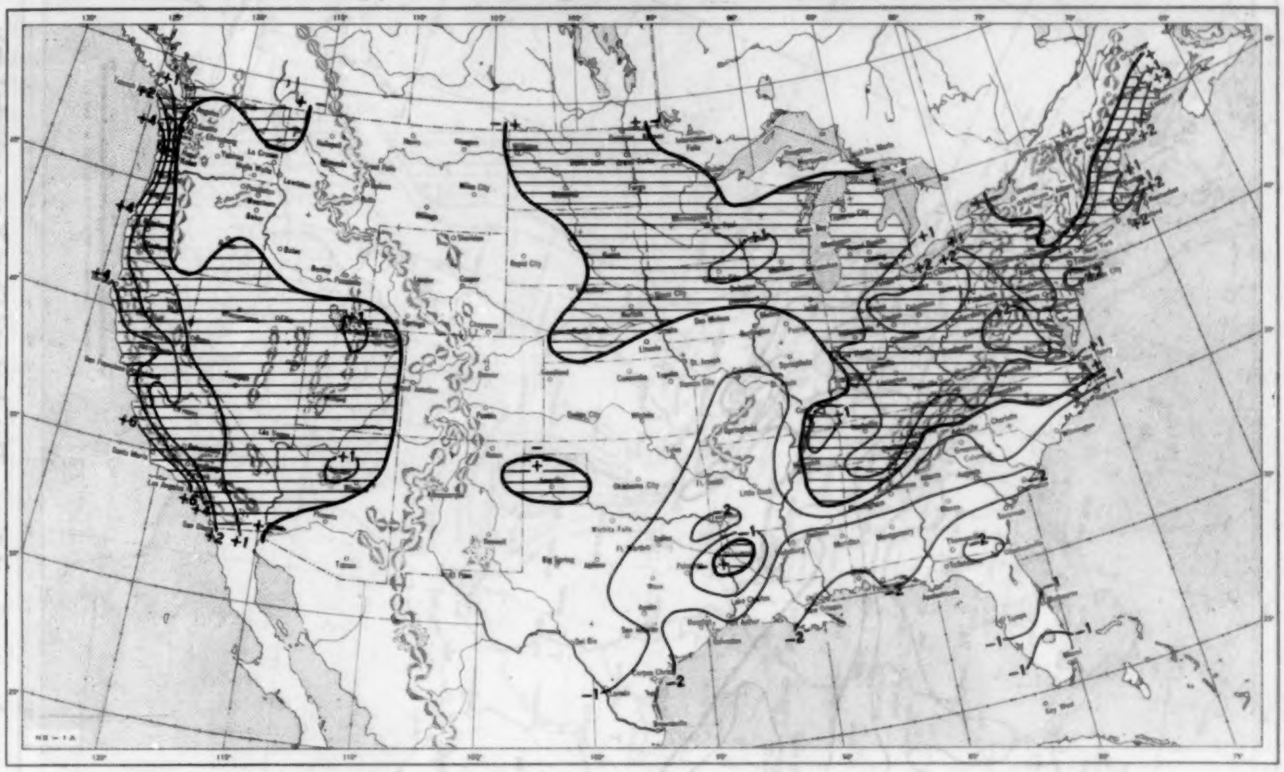
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), January 1952.

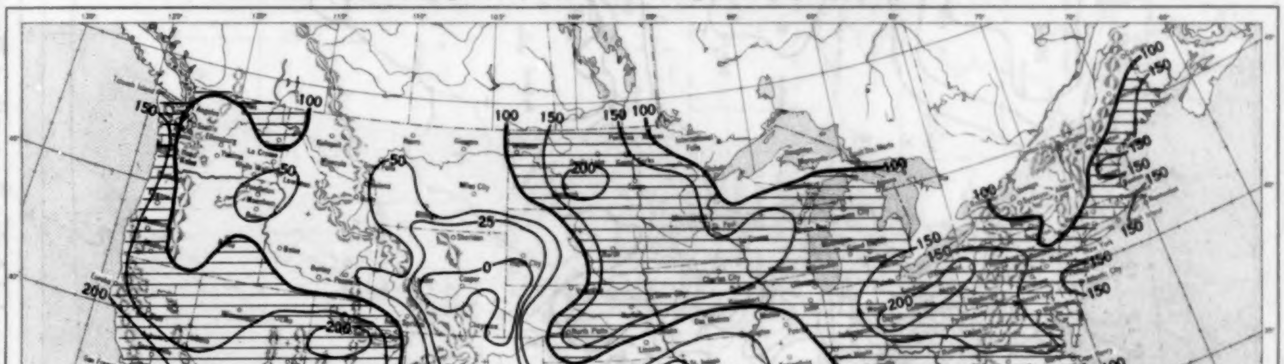


Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), January 1952.

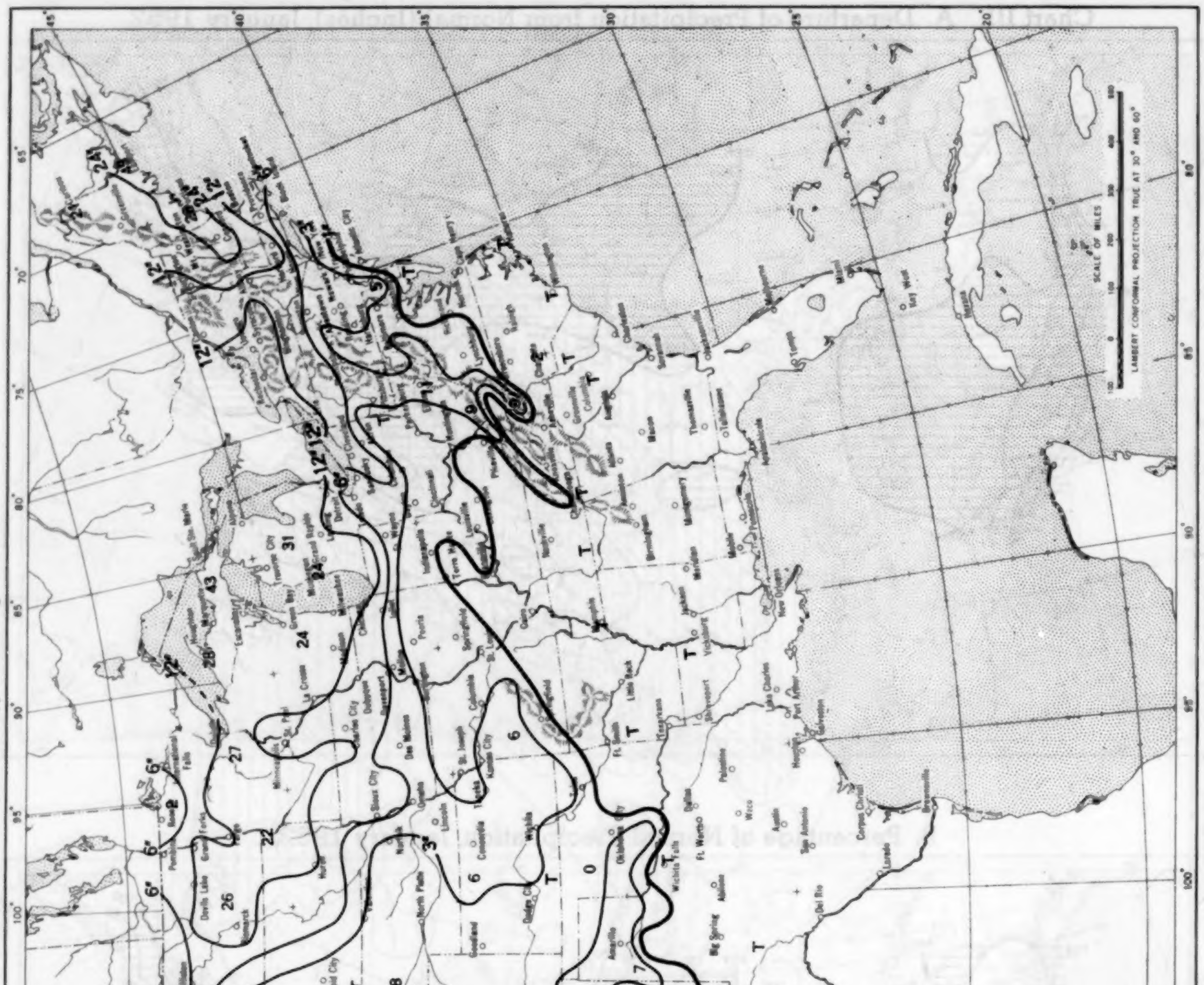


B. Percentage of Normal Precipitation, January 1952.



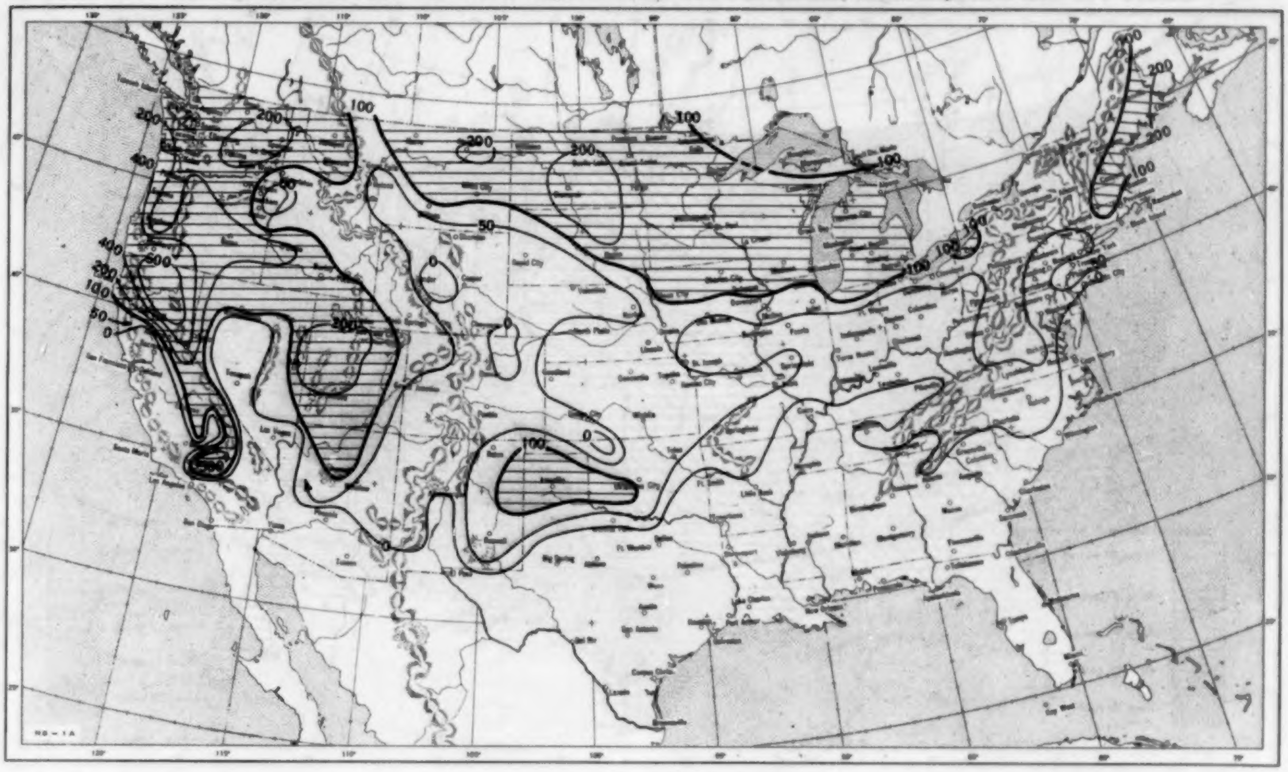
Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), January 1952.

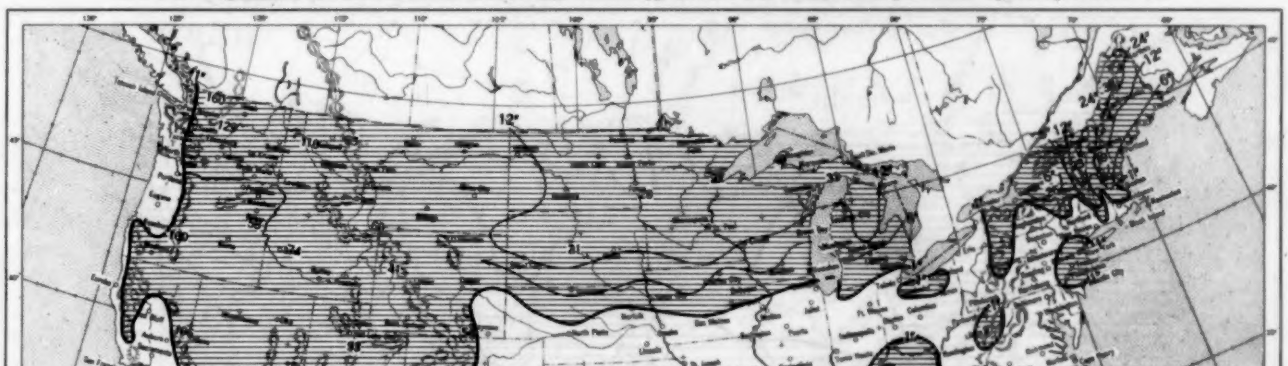


This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

Chart V. A. Percentage of Normal Snowfall, January 1952.

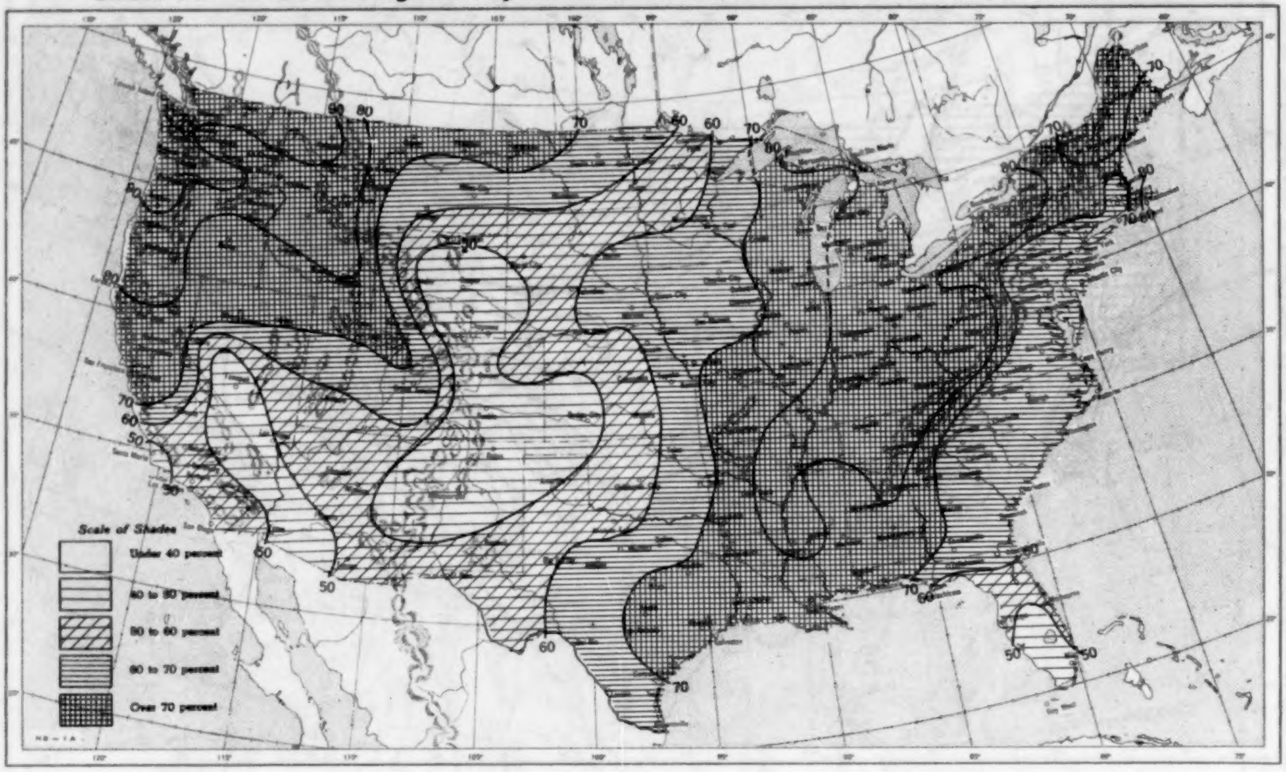


B. Depth of Snow on Ground (Inches), 7:30 a. m. E. S. T., January 29, 1952.

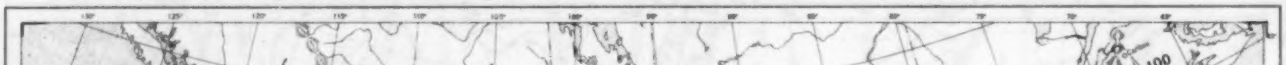


A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E. S. T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, January 1952.

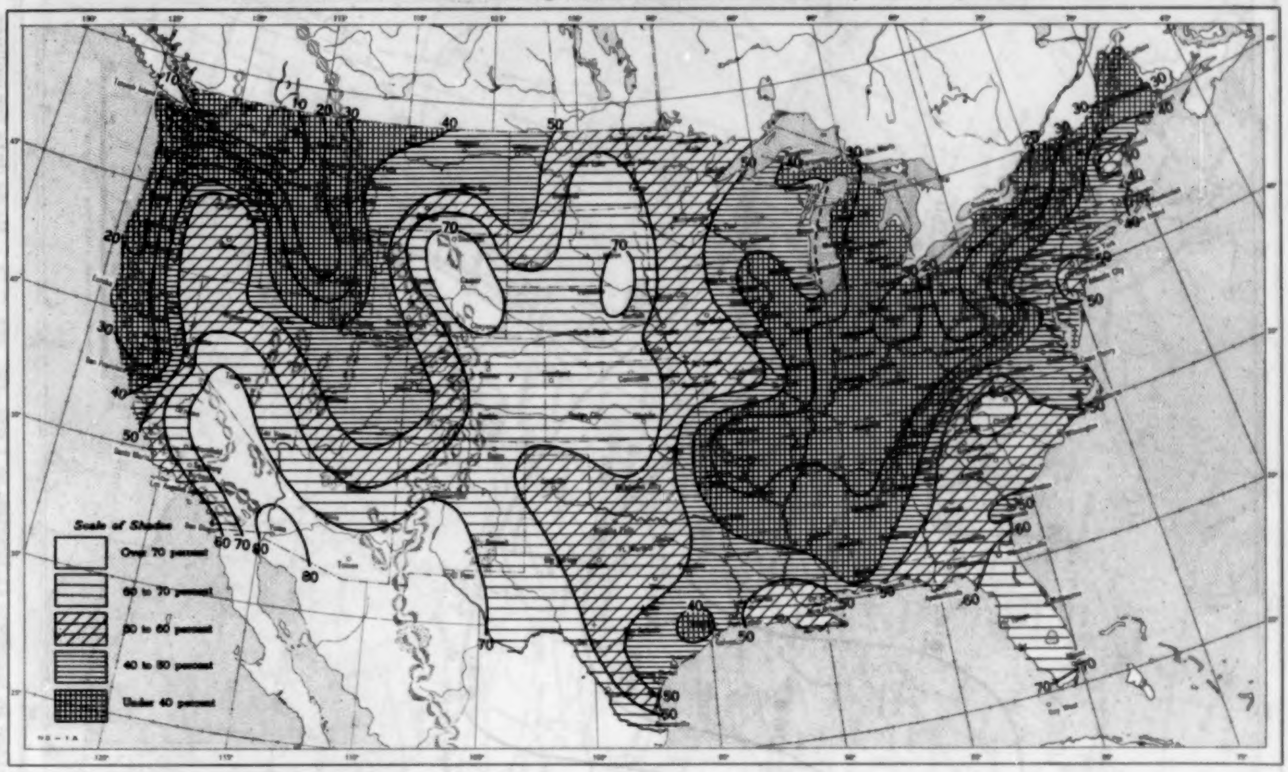


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, January 1952.

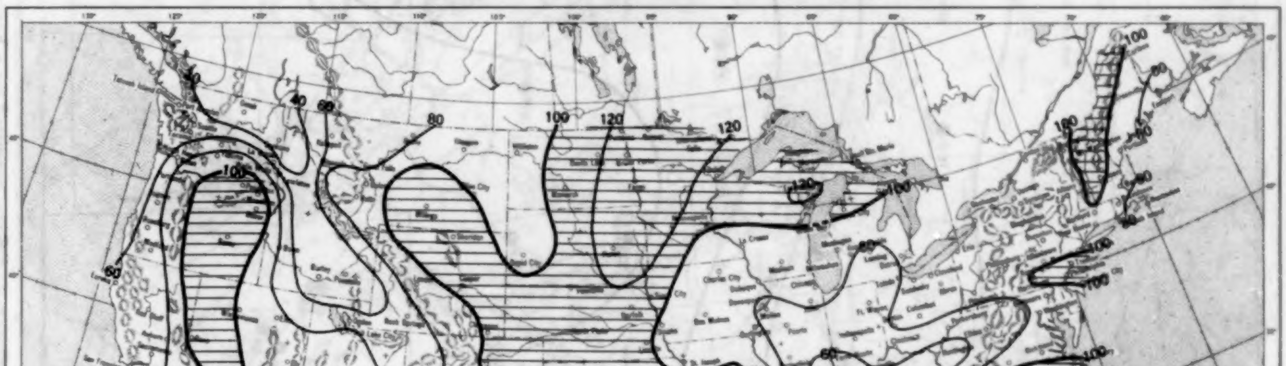


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, January 1952.



B. Percentage of Normal Sunshine, January 1952.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, January 1952. Inset: Percentage of Normal Average Daily Solar Radiation, January 1952.

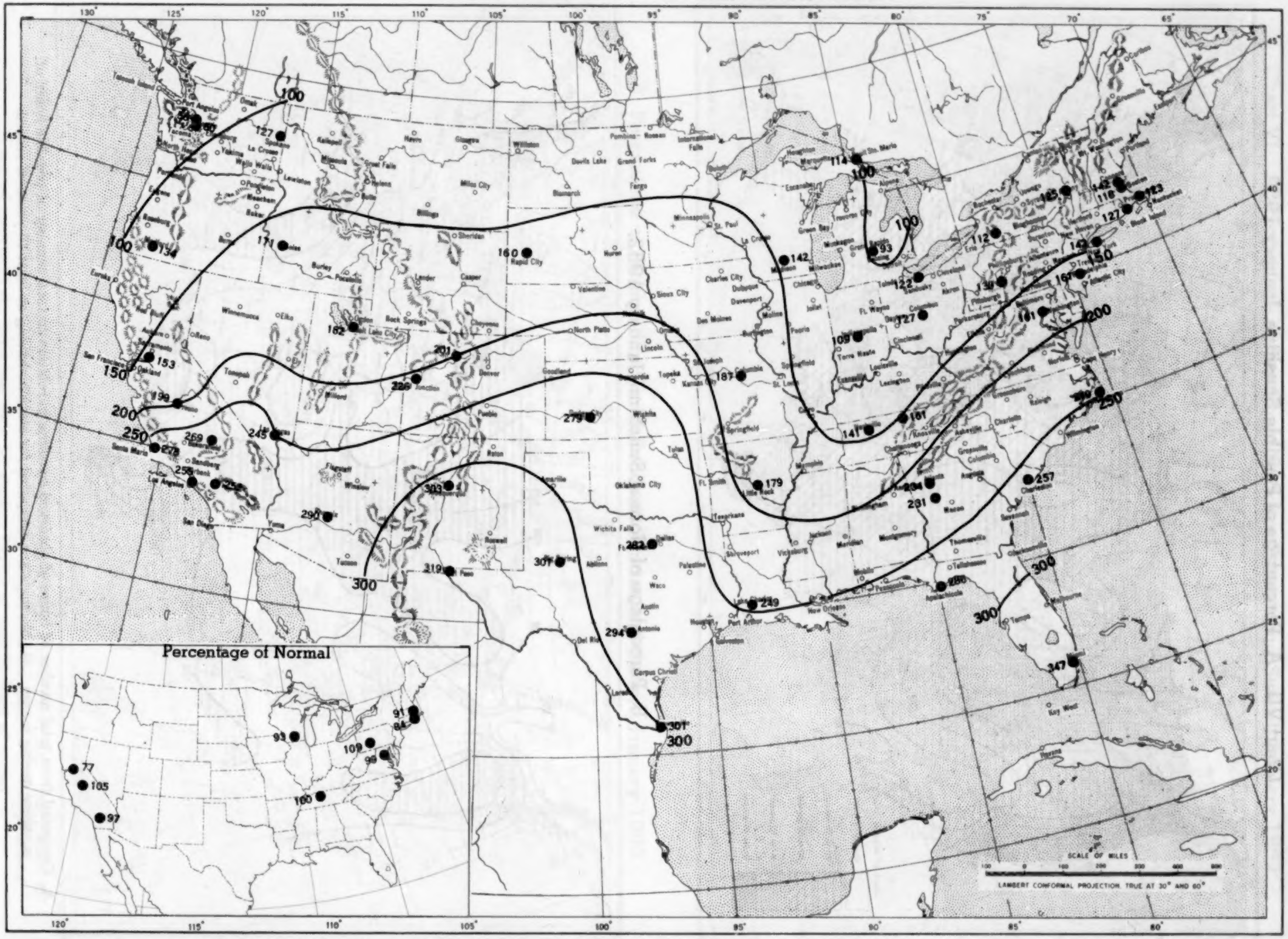
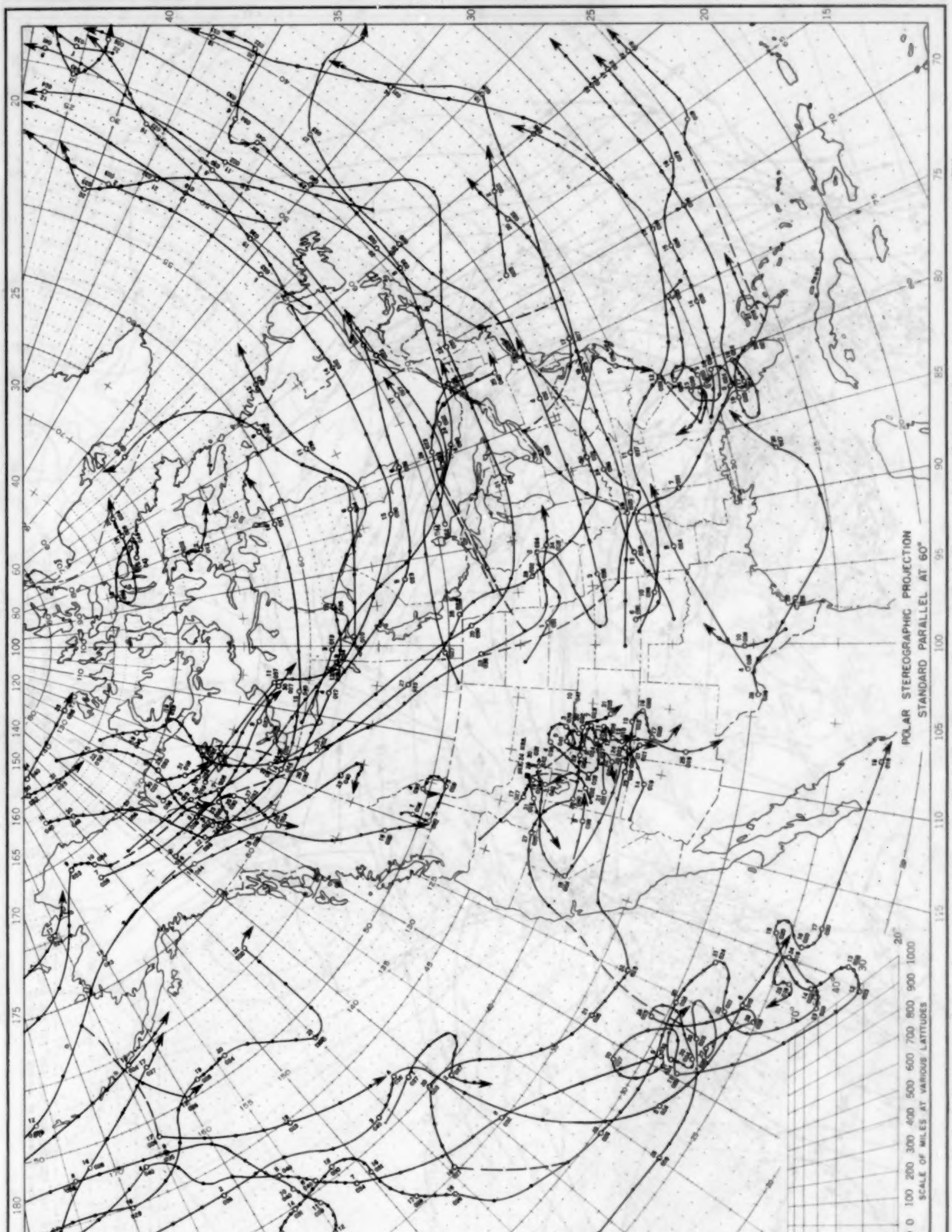


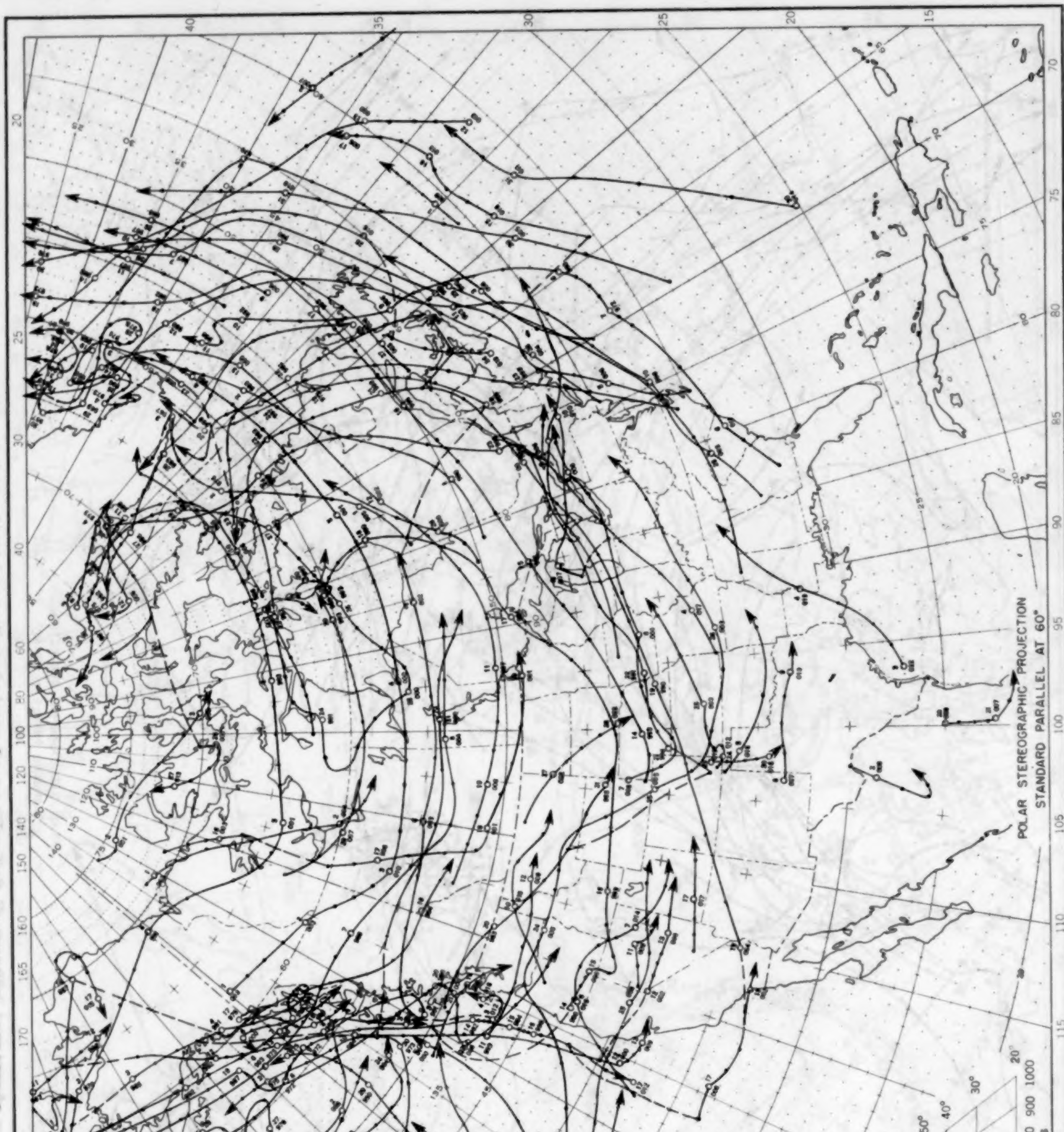
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm.$^{-2}$). Basic data for isolines are shown on chart. Further estimates obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, January 1952.



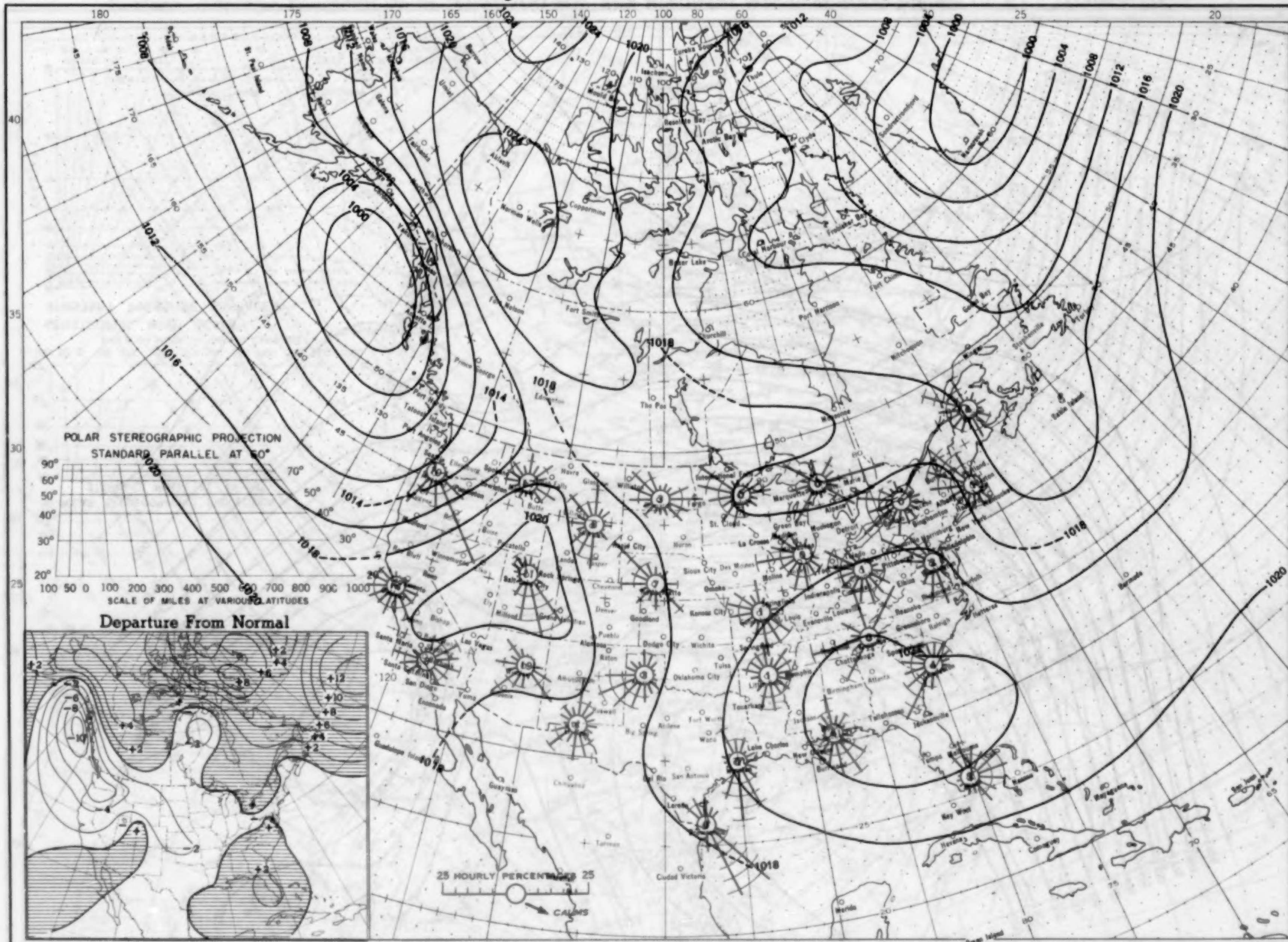
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, January 1952.



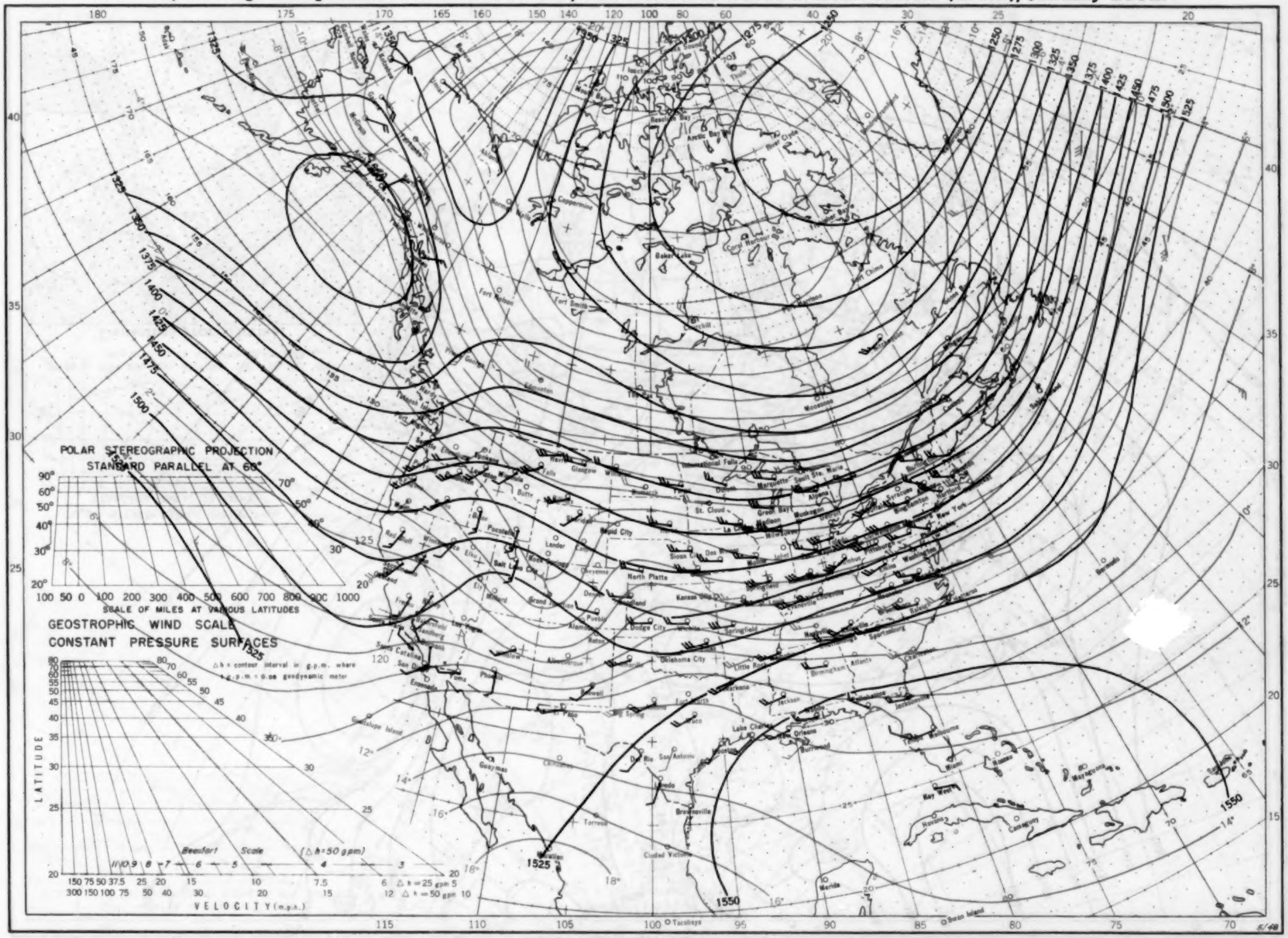
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, January 1952. Inset: Departure of Average Pressure (mb.) from Normal, January 1952.



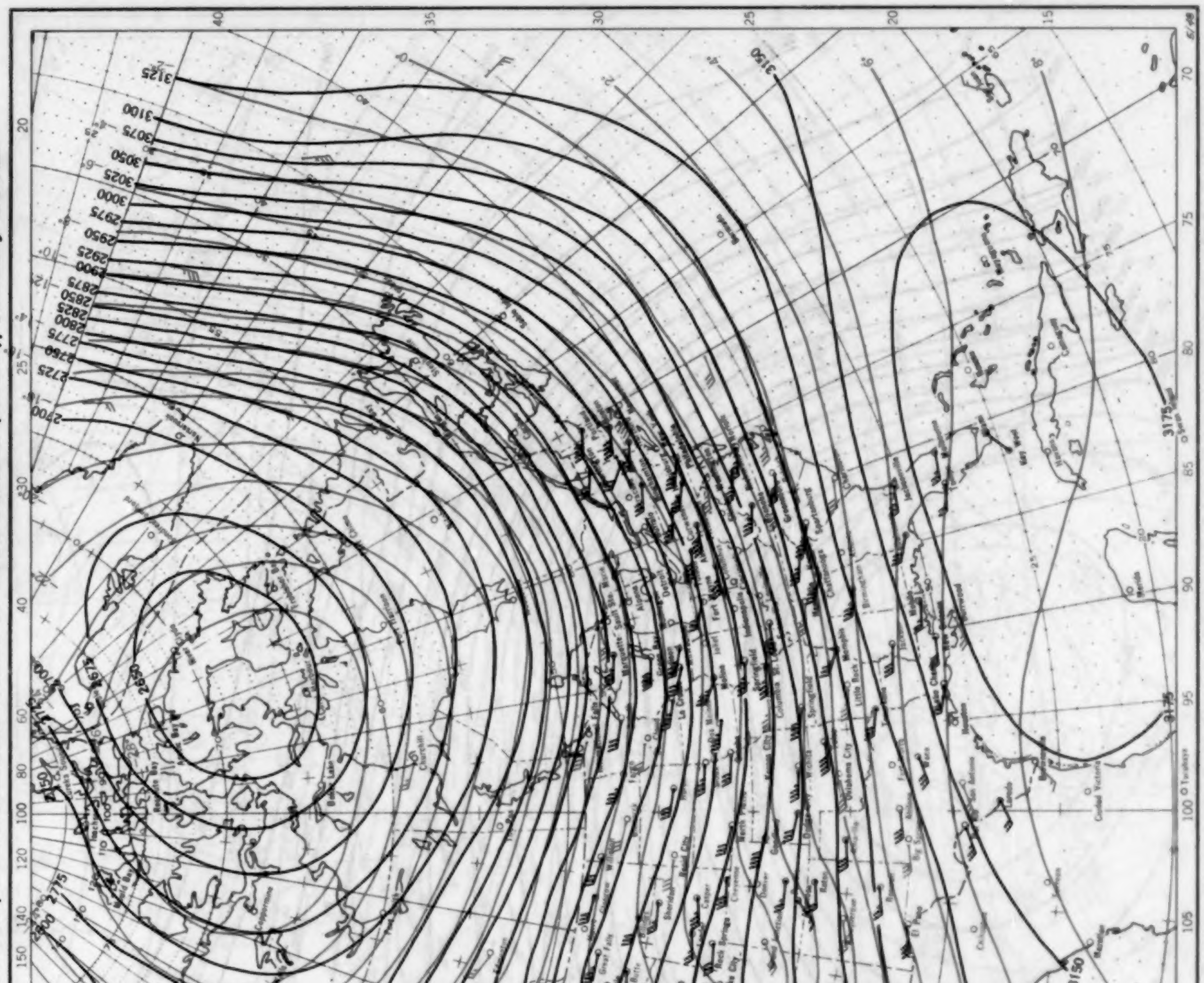
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), January 1952.



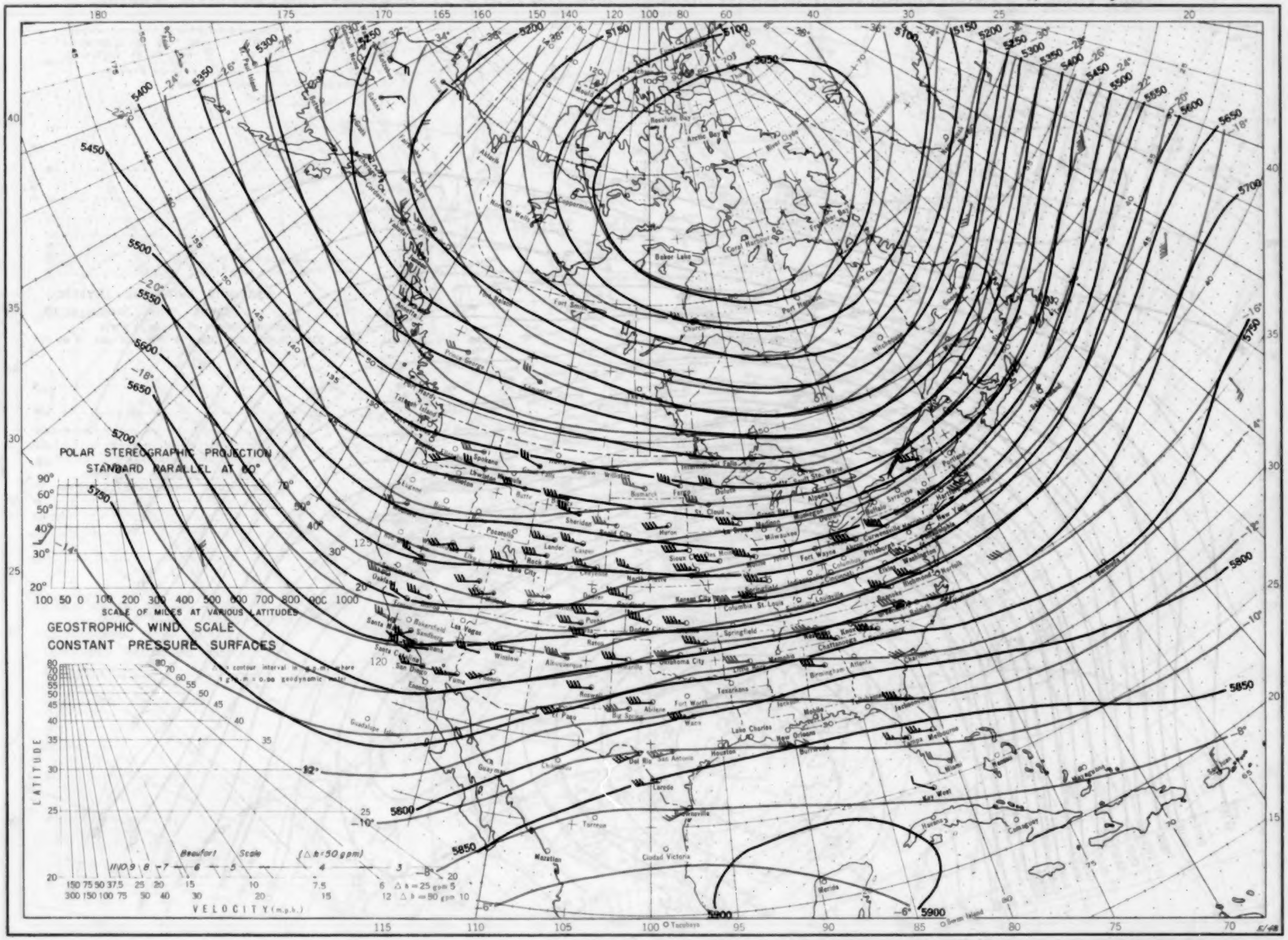
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), January 1952.



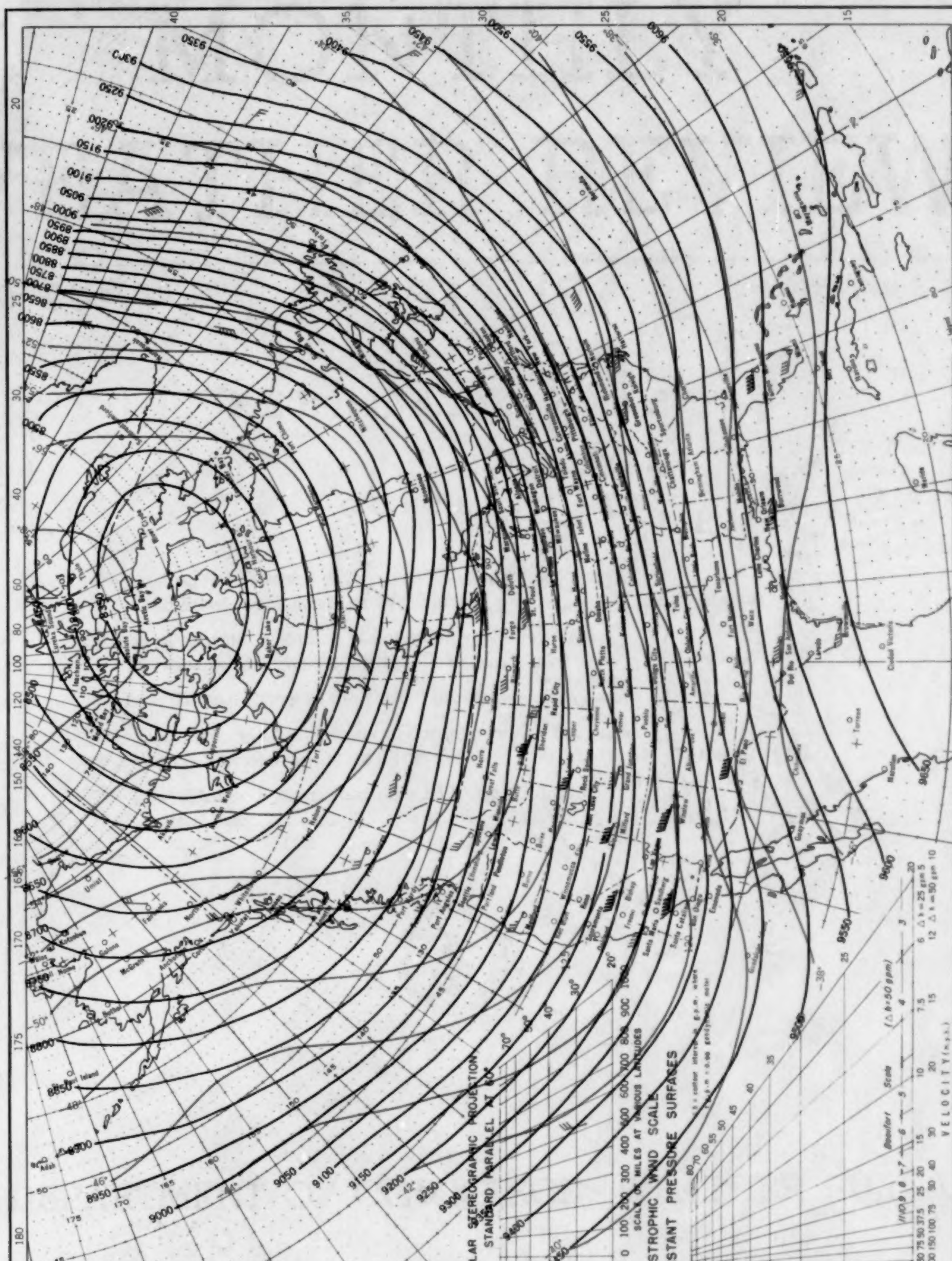
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), January 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), January 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.